(NASA-CR-134127) LIGHTWEIGHT TIRE CONCEPT FOR SPACE SHUTTLE Final Report (Goodrich (B. F.) Co.) 47 p HC $4.50 CSCL 22B

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NASA CONTRACT No. NAS 9-12049
DRL NO. T-685
LINE ITEM NO. 9
DRD NO. MA-129T

CR-134127

BFG DOCUMENT NUMBER ATD-2751

FINAL TEST REPORT

LIGHTWEIGHT TIRE CONCEPT

FOR

SPACE SHUTTLE

OCTOBER 30, 1973

THE B.F.GOODRICH COMPANY

AKRON, OHIO

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Aircraft Tire Development

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THE B.F.GOODRICH COMPANY

AKRON, OHIO

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ABSTRACT

This section of the final report summarizes the work done in evaluating and testing a lightweight tire. This work was done under NASA Contract Number NAS 9-12049 that also included evaluating and testing a lightweight wheel and brake. The work on the wheel and brake was done by the B.F.Goodrich Aerospace and Defense Products Division at Troy, Ohio.

All of the various tests were conducted on a 49x17/26 PR aircraft tire that had been designed as a lightweight tire for use on the C-5A military transport. This tire is approximately 25 per cent lighter than a tire of the same size and ply rating that would be used in commercial airline service.

The tires were tested at 40 per cent, 37 per cent and 35 per cent deflections. These deflections were obtained by adjusting the inflation pressure while the load on the tire remained constant at 60,000 pounds. It was determined that the tire would operate successfully under the test conditions at 35% deflection. Prior to testing, the tires were subjected to conditions of high vacuum and low temperature. It was determined that the tires were not adversely affected by these conditions.

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DEFINITIONS

% Deflection

The difference between the loaded and unloaded section heights of the tire divided by the unloaded section height above the top of the rim flange multiplied by 100.

d = deflection (difference between loaded and unloaded section heights)

FH = free height (unloaded section height above the top of the rim flange)

B = % deflection

$$B = \frac{d}{FH} \times 100$$

This value is a measure of the stresses that a tire must withstand due to the deformation of the tire as it revolves.

It must be noted that the inflation pressure required to obtain a given % deflection on a flat surface is not the same as the pressure required to obtain this same % deflection when the tire is loaded against a curved dynamometer roadwheel. The inflation pressures used for the dynamic tests were those required to obtain the required % deflection on the curved dynamometer roadwheel.

Burst Factor

The value obtained by dividing the inflation pressure at which a tire will burst by the normal operating inflation pressure. This value is a measure of the severity of the stresses a tire must withstand due to the inflation pressure within it.

TEST RESULTS

(1)	Tire Test Number	N83-1208 -2	N83-1208 -3	N83-1208 -4	N83-1208 -5	N83-1208 -6
(2)	Tire Serial Number	1229AK0596	1228AK0595	1224AK0642	1159AK0268	1161AK0200
(3)	Tire Load (Pounds)	60,000	60,000	60,000	60,000	N/A
(4)	Maximum Speed (MPH)	207	207	207	207	N/A
(5)	% Deflection	40	37	35	35	N/A
(6)	Vacuum Chamber	No	No	No	Yes	Yes
(7)	7-Day Cold Soak	Yes	Yes	Yes	Yes	No
(8)	Take-Off Cycles	5	5	5	10	0
(9)	Landing Cycles	5	5	5	10	0
(10)	Taxi Cycles	10	10	10	20	0
(11)	Inflation Prior To Cold Soak (PSI)	291	323	350	350	N/A
(12)	Inflation After Cold Soak (PSI)	194	217	195	240	N/A
(13)	Max. Tire Inflation During Landing-Taxi After Cold Soak (PSI)	306	333	297	346	N/A
(14)	Max. Tire CAT* During Landing-Taxi After Cold Soak (°F.)	134	124	139	**	N/A
(15)	Inflation Prior to Landing-Taxi or Taxi-Take-Off (PSI)	223	247	268	268	N/A
(16)	Max. Tire Inflation During Landing-Taxi (PSI)	274	285	295	312	N/A
(17)	Max. Tire CAT* During Landing-Taxi (°F.)	180	168	170	180	N/A
(18)	Max. Tire Inflation During Taxi-Take-Off (PSI)	265	280	287	310	N/A
(19)	Max. Tire CAT* During Taxi-Take-Off (°F.)	189	189	186	186	N/A
(20)	Burst Pressure (PSI)	N/A	N/A	N/A	640	800
(21)	Condition of Tire After Testing	Unsatis-factory	Unsatis-factory	Satis-factory	Satis-factory	Satis-factory

*Contained Air Pressure.
**Not Recorded.

CONCLUSIONS

Prolonged exposure to conditions of low temperature or high vacuum does not adversely affect a pneumatic tire constructed of materials commonly used for the manufacture of tires for conventional aircraft.

A tire manufactured using materials and construction techniques commonly utilized when minimum tire weight is a major design factor is capable of operating at 35 per cent deflection with a rated inflation pressure that is 33 per cent of its ultimate burst strength. A tire so constructed is also capable of withstanding the increased inflation pressure at normal ambient temperature that is required to maintain the rated inflation pressure at a contained air temperature of -55°F.

RECOMMENDATIONS

The conclusions reached are based on data obtained from very limited testing. This testing was conducted under conditions that were at best a very rough estimate of what a tire might be subjected to in actual service. More extensive testing should be conducted when better estimates of actual service conditions are available.

One tire was subjected first to a high vacuum, then to a low temperature and finally to dynamic testing. A tire should be subjected to both high vacuum and low temperature simultaneously.

After the 35 per cent deflection was determined to be the maximum that could be used successfully, only one tire was subjected to further testing under these conditions. Further testing should be conducted in order to establish some sort of reliability index. The most important factor for which a reliability index must be established is the ability of the tire and wheel assembly to maintain the proper inflation pressure under conditions of high vacuum and low temperature.

DISCUSSION

The objective of this portion of the work done under NASA Contract Number NAS 9-12049 was to establish a set of tire design criteria which would provide a tire that is lighter than current designs, would meet orbiter environmental conditions and would meet the load conditions imposed by orbiter operations.

In order to establish these criteria, an existing 49x17/26 PR aircraft tire was subjected to conditions of load and inflation that are more severe than those for which the tire was originally designed. The tire is designed to operate at a maximum load of 39,600 pounds with an inflation pressure of 170 PSI which results in a 32 per cent deflection. The minimum burst pressure is four times the rated inflation or 680 PSI. Quality Control checks have shown that the average burst pressure is 723 PSI $\pm$ a deviation of 43 PSI.

Tire weight is a function of inflation pressure. The ability of a tire to contain the air pressure within it is dependent on the strength of the carcass fabric and bead wire with which the tire is constructed. A decrease in the inflation pressure that a tire must contain leads to a corresponding decrease in the amount of fabric and wire used in building the tire and thereby a decrease in tire weight. A decrease in inflation pressure can be realized if a tire is allowed to operate at a higher than normal per cent deflection. Tire weight can also be reduced if the tire is allowed to operate at an inflation pressure that is closer than normal to its ultimate burst strength. This value of burst inflation divided by operating inflation is called the burst factor and is normally four or greater for conventional aircraft tires.

The dynamic tire tests were conducted using a load of 60,000 pounds with the inflation pressure adjusted to give 40 per cent, 37 per cent and 35 per cent deflections. Each of the four dynamic tested tires were first subjected to the cold soak conditions before undergoing the first landing-taxi cycle. This cold soak was designed to simulate the environment the tire would see in space. The additional landing-taxi and taxi-take-off cycles were designed to simulate the ferrying operations. A copy of B.F.Goodrich Standard Dynamic Test 4917-NASA is in Appendix A.

Special test wheels are normally used for dynamometer testing in order to obtain the required instrumentation. The initial attempts at running the cold soak tests were unsuccessful due to the inability of the test wheel O-ring to withstand the -65°F. temperature. In addition to a standard O-ring, both an ethylene-propylene compounded and a silicone compounded O-ring were tried unsuccessfully. After these failures, a standard production wheel was tried.

DISCUSSION (Cont'd)

It was determined that there was no excessive inflation loss with the production wheel. However, further attempts were made using an inner tube with the test wheel. Satisfactory air retention was obtained with this configuration and tests showed that tire dynamic deflection characteristics were not affected. All cold soak, landing-taxi cycles were run with an inner tube in the tire. The inner tube was then removed prior to the remaining conventional taxi-take-off and landing-taxi cycles.

Test Tire No. N83-1208-2 (Serial #1229AK0596) was subjected to the cold soak conditions and then run through a series of landing-taxi and taxi-take-off cycles. The tire was run at 40 per cent deflection. Upon completion of the testing, the tire was cut and examined and found to have separations of the carcass fabric in the ply turn-up area of the lower sidewall. These separations were quite extensive in size.

Test Tire No. N83-1208-3 (Serial #1228AK0595) was subjected to identical cold soak and landing-taxi and taxi-take-off cycles. However, the inflation pressure in the tire was increased in order to achieve a 37 per cent deflection condition. This tire was cut and found to have separations at the turn-up endings of two plies.

Test Tire No. N83-1208-4 (Serial #1224AK0642) was also subjected to identical cold soak and landing-taxi and taxi-take-off cycles. The inflation pressure in this tire was further increased to obtain a 35 per cent deflection condition. It must be noted that the inflation pressures recorded during the landing-taxi cycle, that immediately followed the cold soak, are lower than what they should have been to achieve the 35 per cent deflection. The minimum tire inflation of 195 PSI indicates that the tire ran through this one cycle at 40 per cent deflection. The tire evidently developed a leak during the cold soak. The remainder of the taxi-take-off and landing-taxi cycles were run at the proper 35 per cent deflection. Analysis of the tire showed minor ply turn-up separations similar to those in the 37 per cent deflection tire.

Test Tire No. N83-1208-5 (Serial #1159AK0268) was subjected to the cold soak conditions. The tire was then run to twice the number of landing-taxi and taxi-take-off cycles as were the previous three tires. The tire was run at 35 per cent deflection. The tire had undergone vacuum chamber testing prior to dynamic testing. The tire was statically burst after the completion of dynamic testing.

Test Tire No. N83-1208-6 (Serial #1161AK0200) was subjected to vacuum chamber testing and statically burst. This tire was not dynamically tested.

APPENDIX A

B.F.GOODRICH STANDARD DYNAMIC TEST 4917-NASA

B.F. GOODRICH AIRCRAFT TIRE STD. DYNAMIC TEST NUMBER	NAS 9-12049 BFG Doc. No. ATD-2751 4917-NASA	SIZE 49x17	26 P.R.
		207	MPH
		TYPE	VII

REFERENCE	NASA RFP No. BC731-50-1-100P

CH.	DESCRIPTION	DATE	BY			
	Proposed	5/7/71	SMP	MAX. RATING	SPEED	207 M.P.H.
	Revised	10/1/71	RHB		LOAD	60,000 LBS.
					INFLATION	202, 224, 235 P.S.I.
					DEFLECTION	40, 37, 35 %
				RIM	SIZE	49x17
					FLGE. DIA.	23.750 IN.
				TEMPERATURE NEEDLE DEPTH	SHOULDER	3/4 IN.
					1/4 IN ABOVE FLGE.	7/8 IN.

1	2	REFERENCE FIGURE		3	
Take-Off A	Landing B	TEST DESCRIPTION		Taxi C	Cold Box "ICE"
		TEST			
		CYCLES PER TEST			
See Below	See Below	TIRE TEMPERATURE BEFORE STARTING TEST (USE CONTAINED AIR TEMPERATURE IF POSSIBLE)		See Below	-55°F. +0-10°F.
202,224,235	202,224,235	INFLATION ON FLAT SURFACE	P.S.I.	202,224,235	
223,247,268	223,247,268	INFLATION 120-INCH WHEEL	P.S.I.	223,247,268	291

Test "ICE":

The tire is to be initially inflated to a pressure which will result in a deflection of 40% once the tire has been removed from the cold box. This pressure is to be determined by calculation and the deflection checked prior to testing. Deflection tolerance to be within +3,-4% of nominal deflection. After inflating the tire in accordance with the above procedure, place the tire in the cold box until such time as the contained air temperature of the tire reaches -65°F.* while the tire is in the cold box, the following items are to be monitored:

(a) Cold Box Temperature
(b) Contained Air Temperature of Tire
(c) Inflation Pressure of Tire

The tire should be removed from the cold box and placed on the dynamometer within twenty minutes.

*A temperature of -65°F. is being used in lieu of -55°F. because of time delay experienced in transferring the tire from the cold box to the dynamometer.

Test "A" - Take-Off:

With the tire loaded to 60,000 pounds, accelerate the flywheel from 0 MPH to 207 MPH at an average rate of 5.7 Ft./Sec.^{2} until a roll distance of 8107 (+200,-0) feet has been covered in approximately 53.3 seconds. The load is to be applied in accordance with Figure 1.

Test "B" - Landing:

Land the tire against the flywheel rotating at 207 MPH and immediately increase the load in accordance with Figure 2. Immediately decelerate the flywheel at a rate of 6.0 Ft./Sec.^{2} until a roll distance of 7706 (+200,-0) feet has been covered in approximately 50.7 seconds, at which time the tire shall be unloaded.

Test "C" - Taxi:

Land the tire against a stationary flywheel at 60,000 pounds load. Immediately accelerate the flywheel, keeping the tire fully-loaded to 5.0 MPH. Taxi the tire at 5.0 MPH until a roll distance of 12,000 (+200,-0) feet has been covered.

Tire Temperature:

Tire temperature prior to all Landing-Taxi cycles and Taxi-Takeoff cycles shall be 110°F.$\pm$10°F. Tire temperature for the Landing-Taxi cycle which immediately follows Test "ICE" shall be -55°F.+0-10°F.

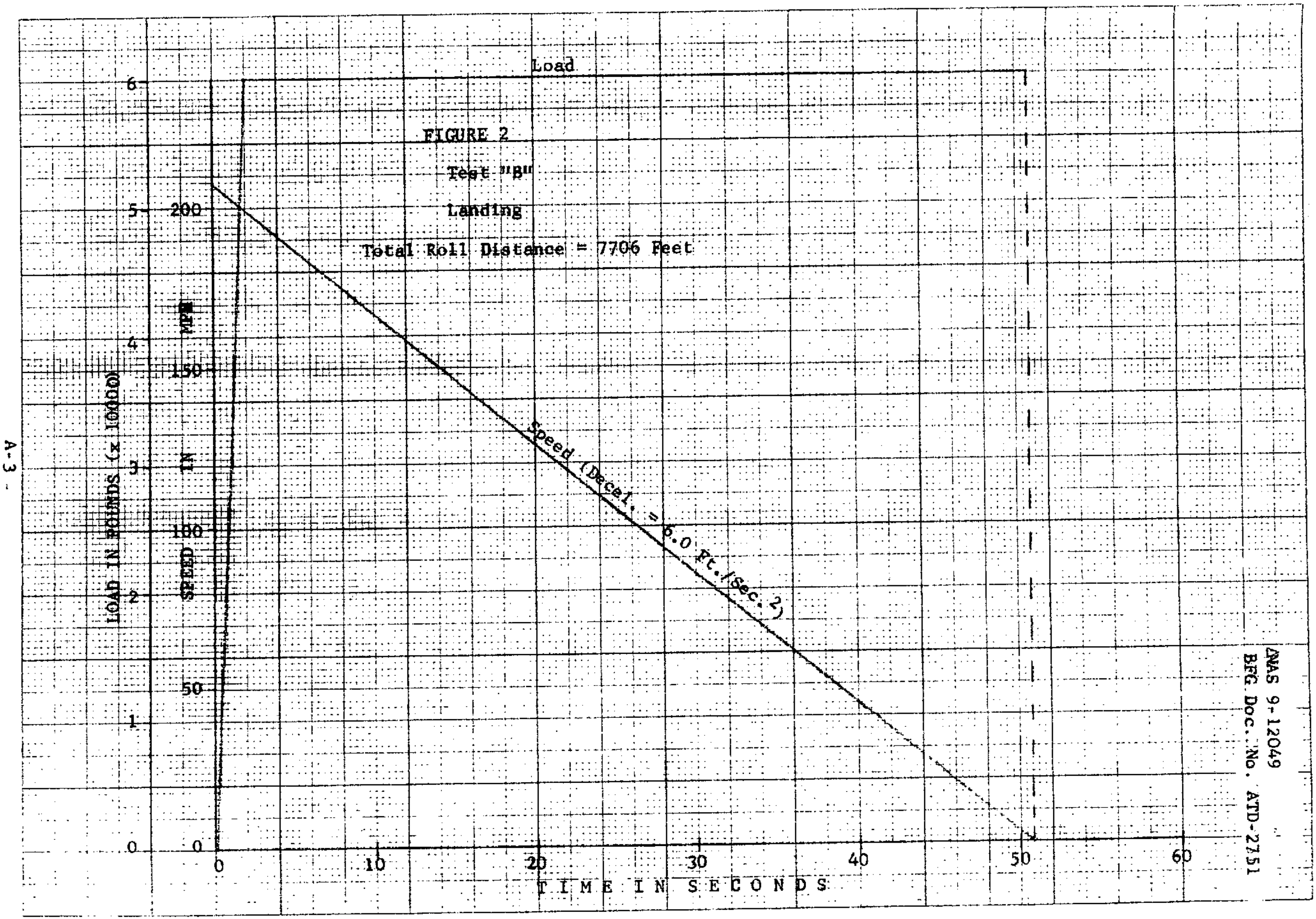


FIGURE 2

Test "B"

Landing

Total Roll Distance = 7706 Feet

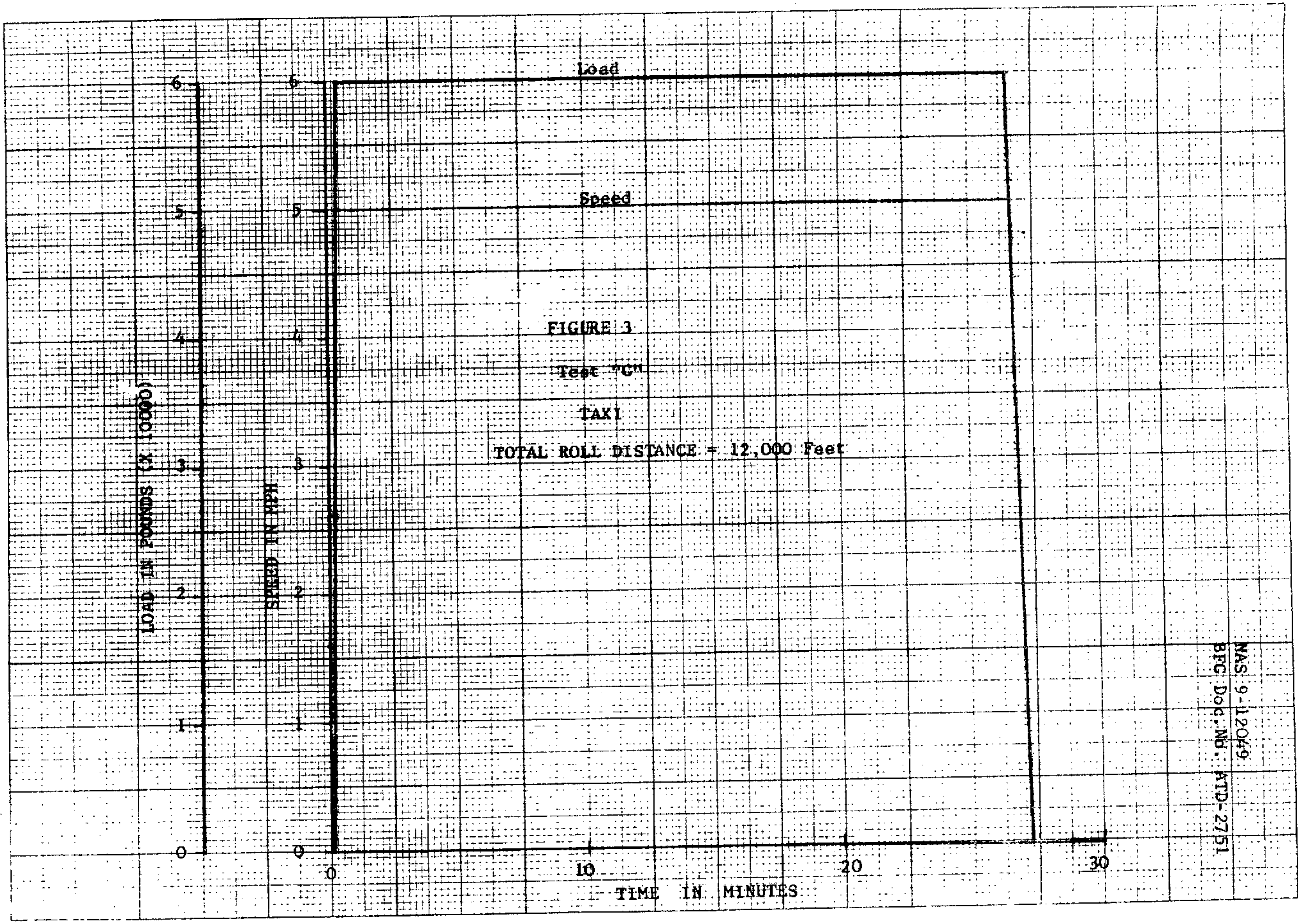
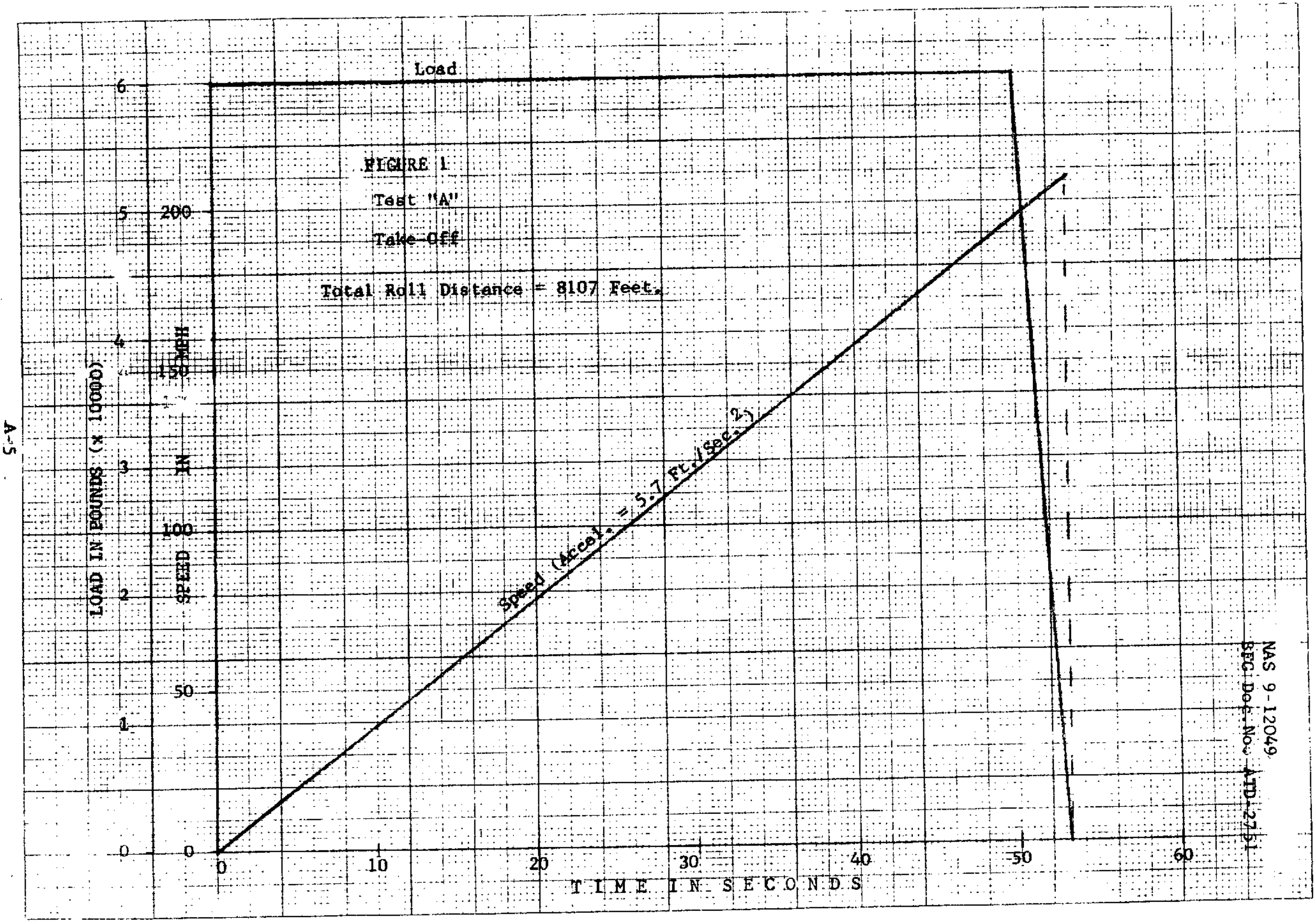


FIGURE 3

Test "G"

TAXI

TOTAL ROLL DISTANCE = 12,000 Feet



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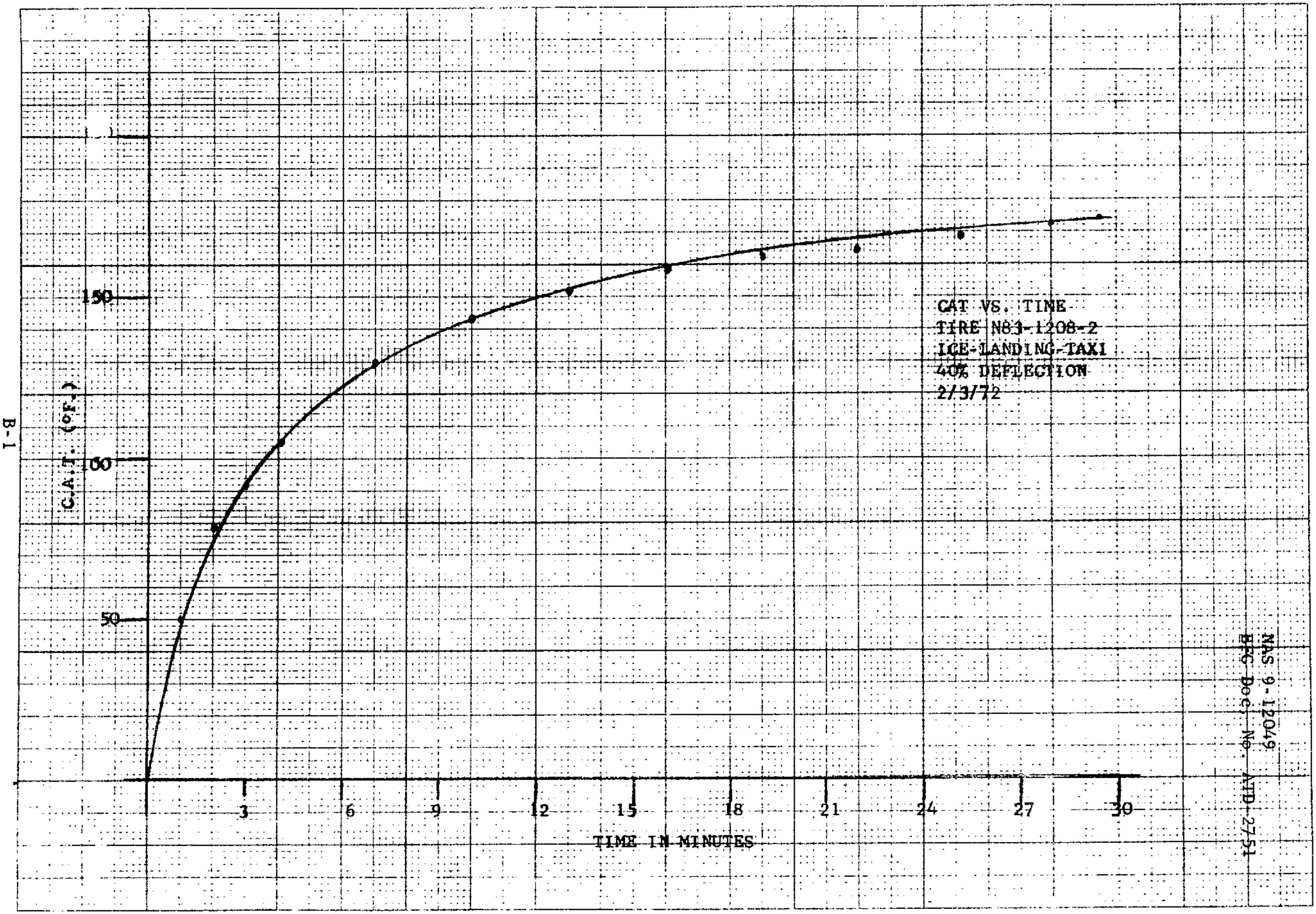
APPENDIX B

CONTAINED AIR TEMPERATURE AND INFLATION PRESSURE DATA



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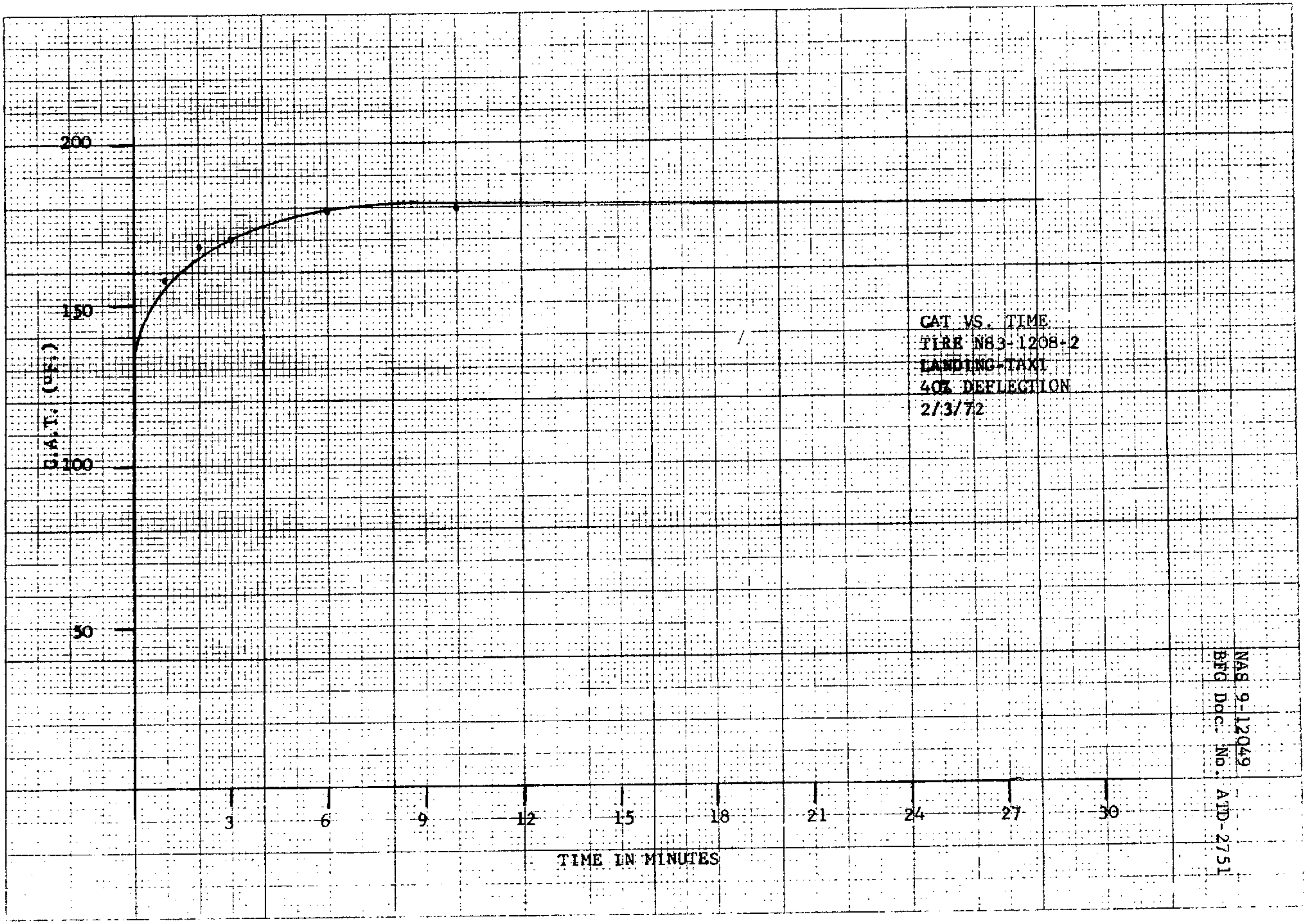

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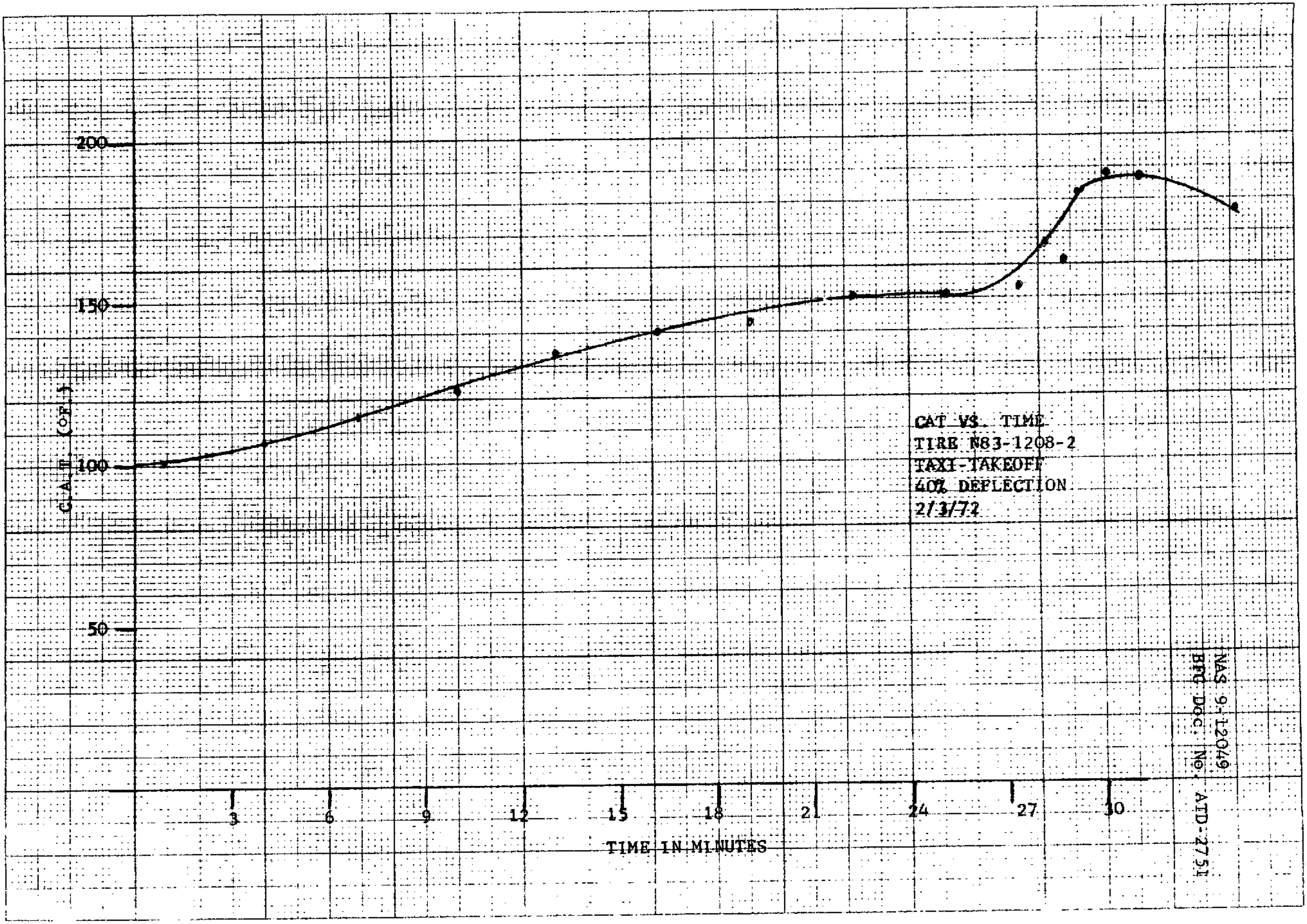

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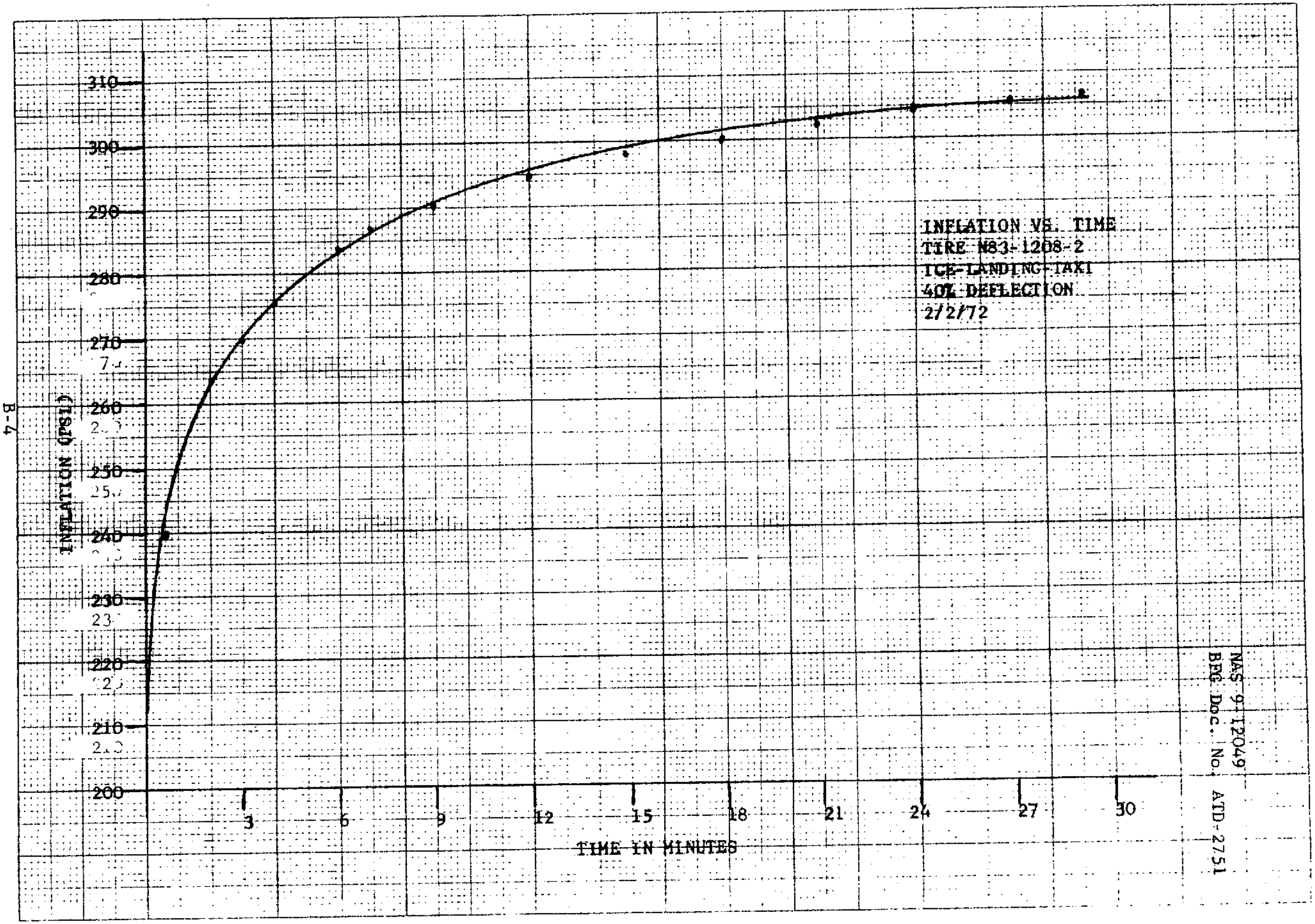

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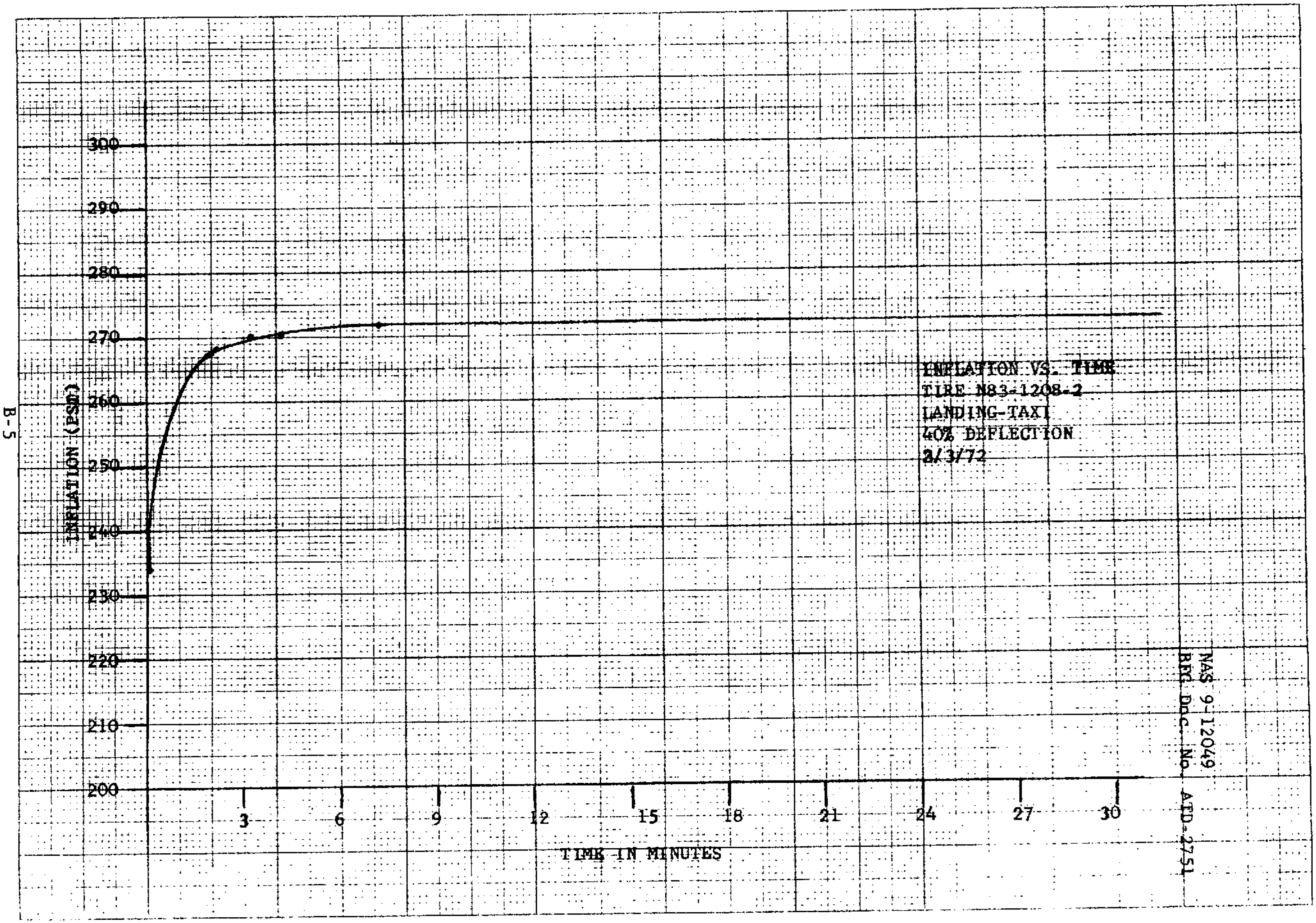

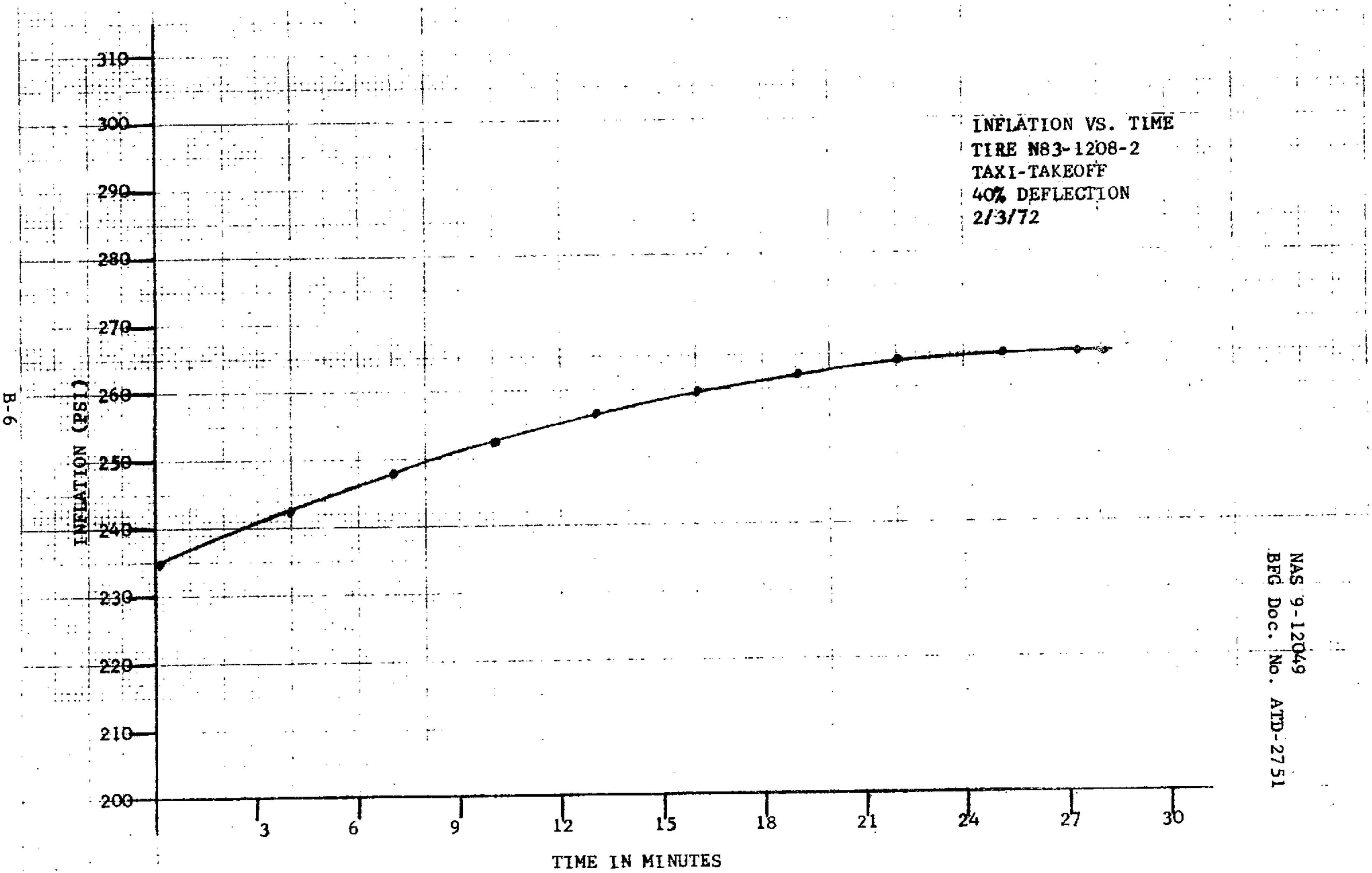
INFLATION VS. TIME
TIRE N83-1208-2
TAXI-TAKEOFF
40% DEFLECTION
2/3/72
INFLATION (PSI)
310
300
290
280
270
260
250
240
230
220
210
200
3
6
9
12
15
18
21
24
27
30
TIME IN MINUTES

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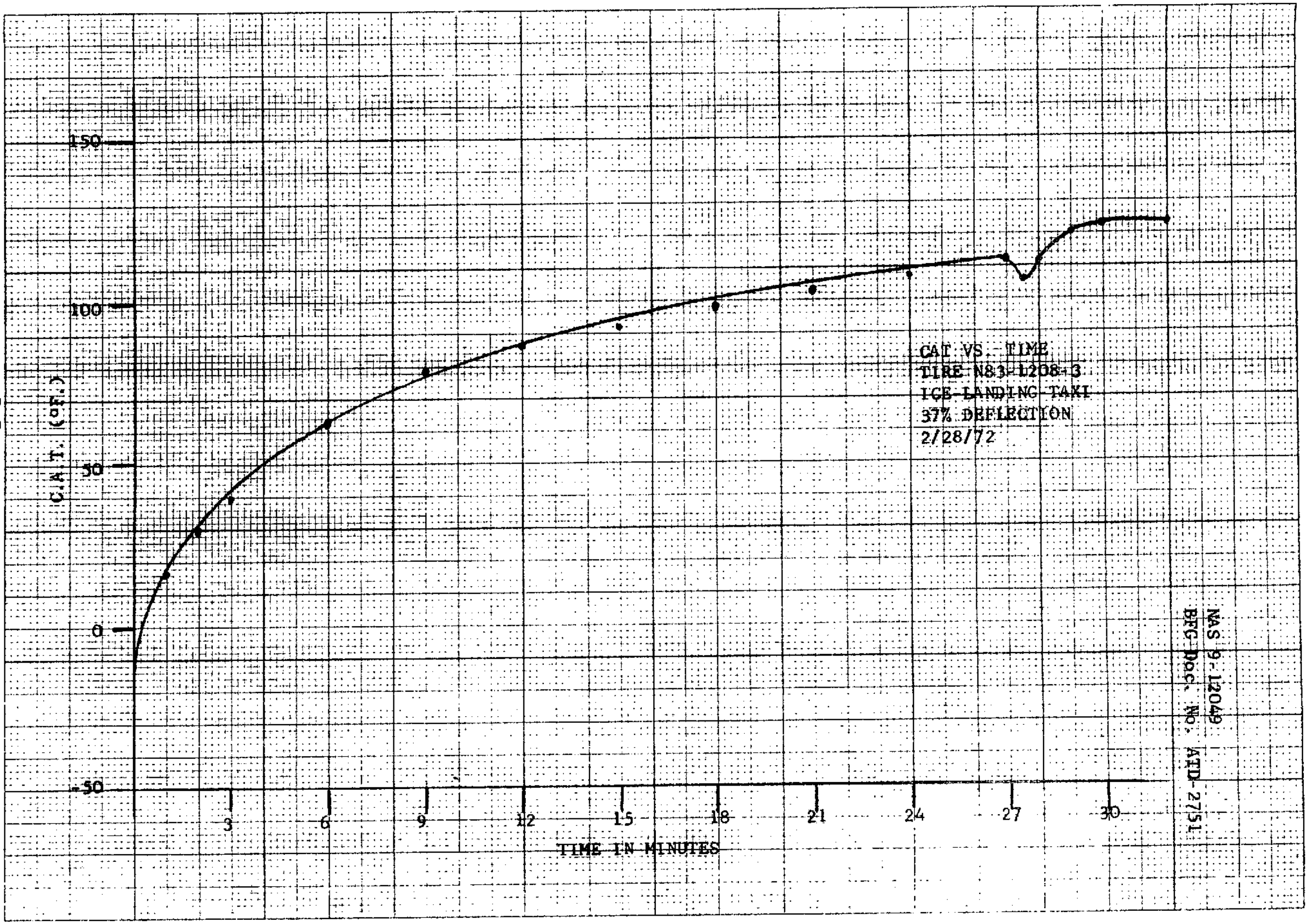

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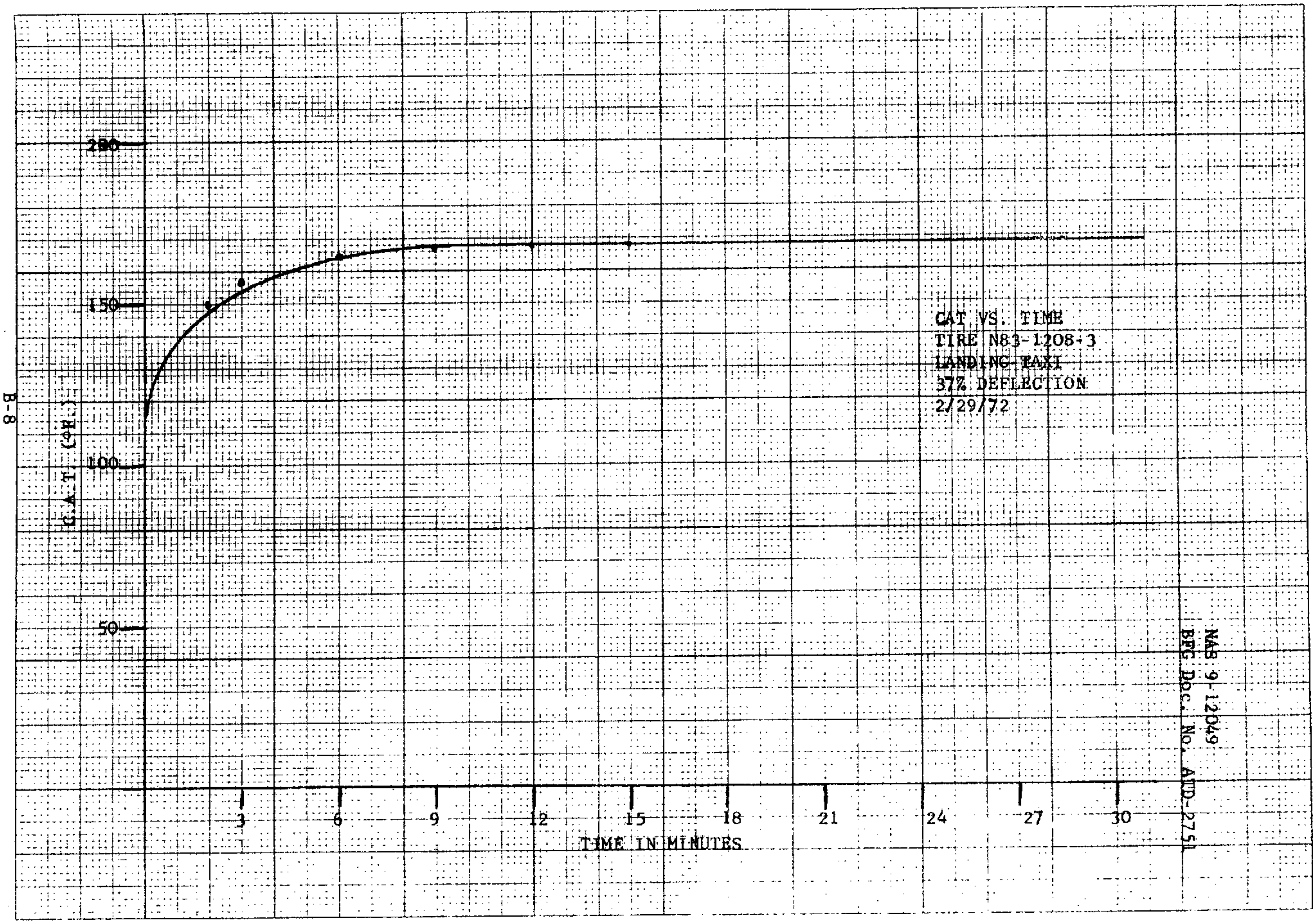

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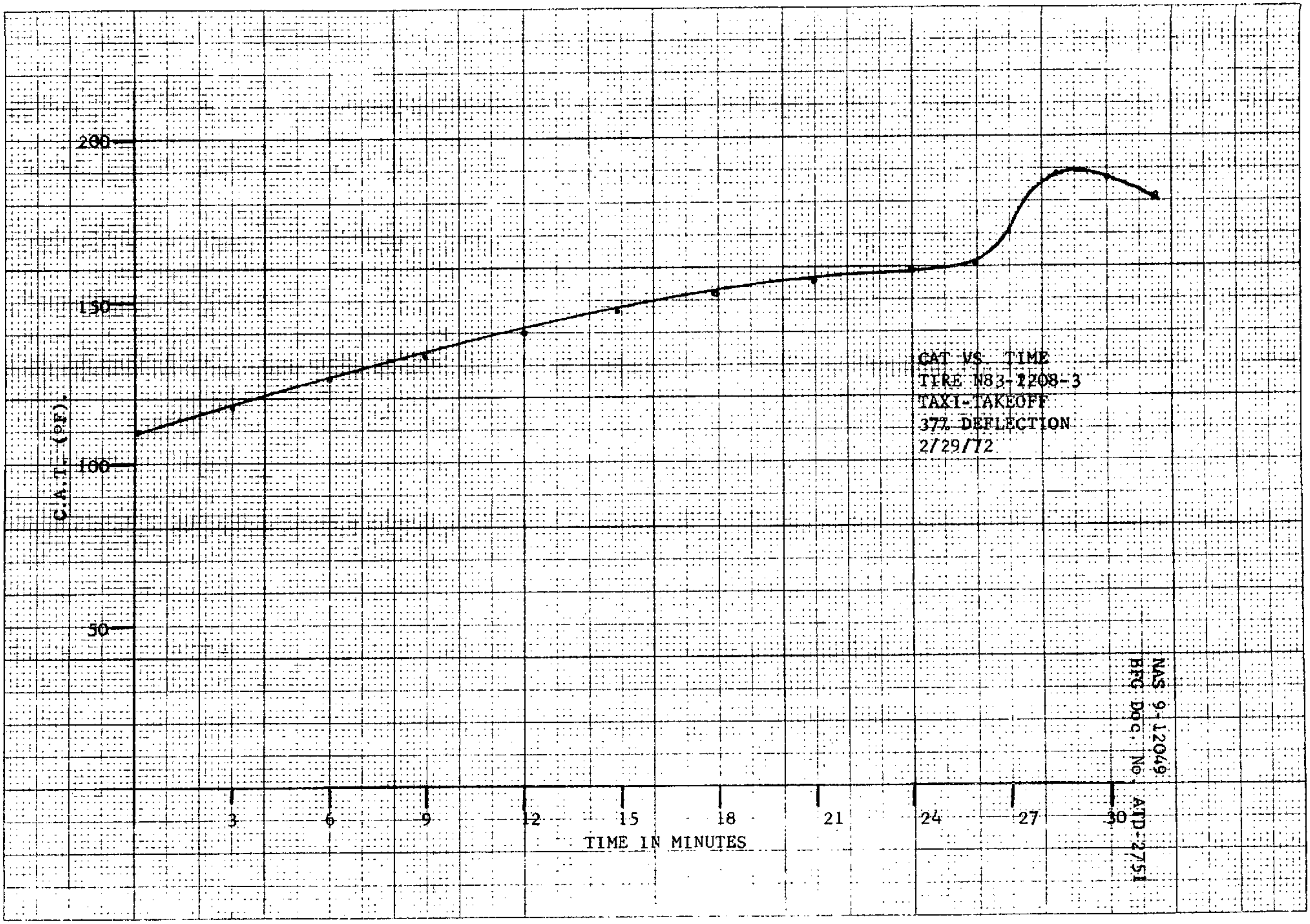
200
150
100
50
C.A.T. (pF)
3
6
9
12
15
18
21
24
27
30
TIME IN MINUTES
CAT VS. TIME
TIRE N83-1208-3
TAXI-TAKEOFF
37% DEFLECTION
2/29/72
NAS 9-12049
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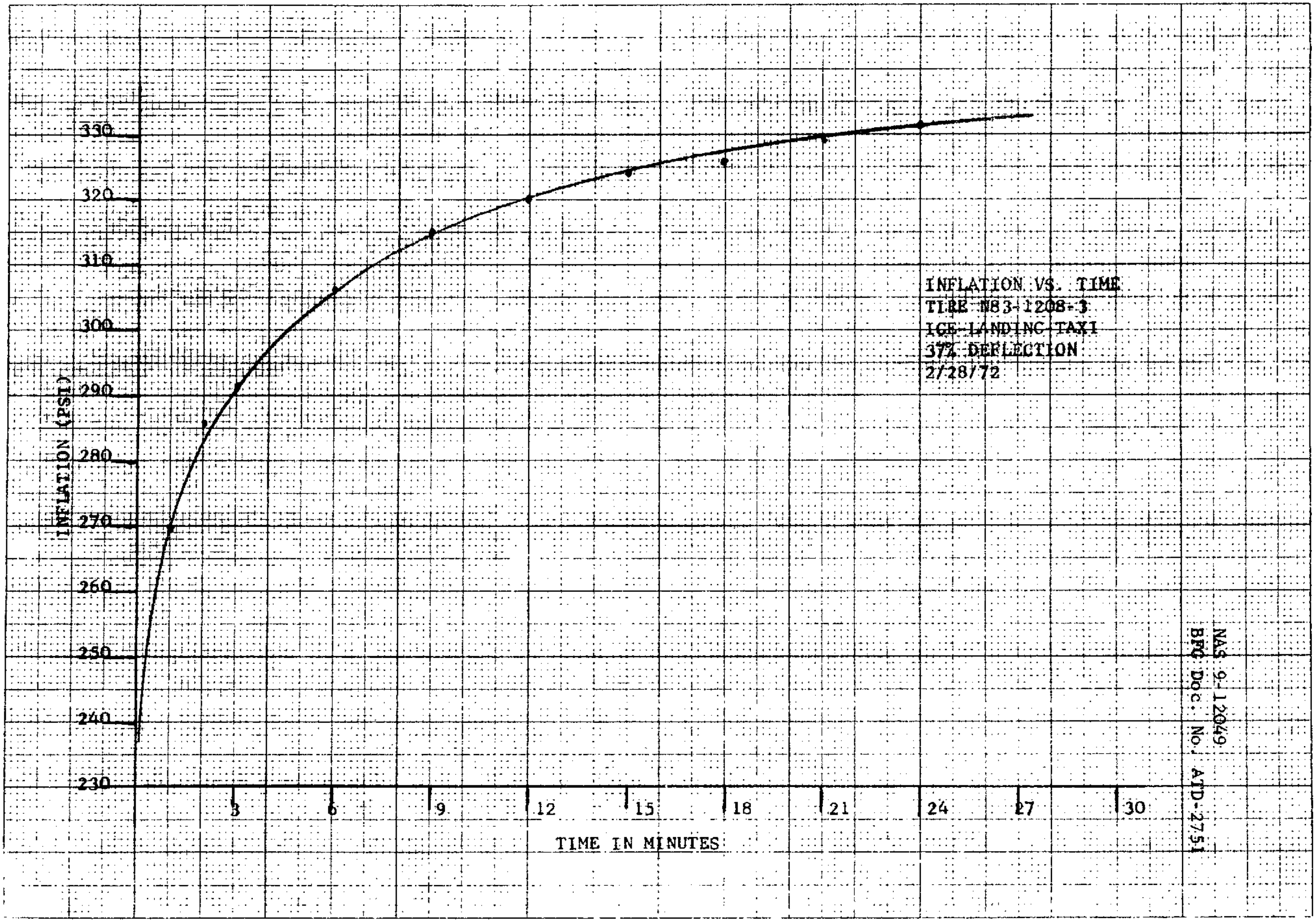

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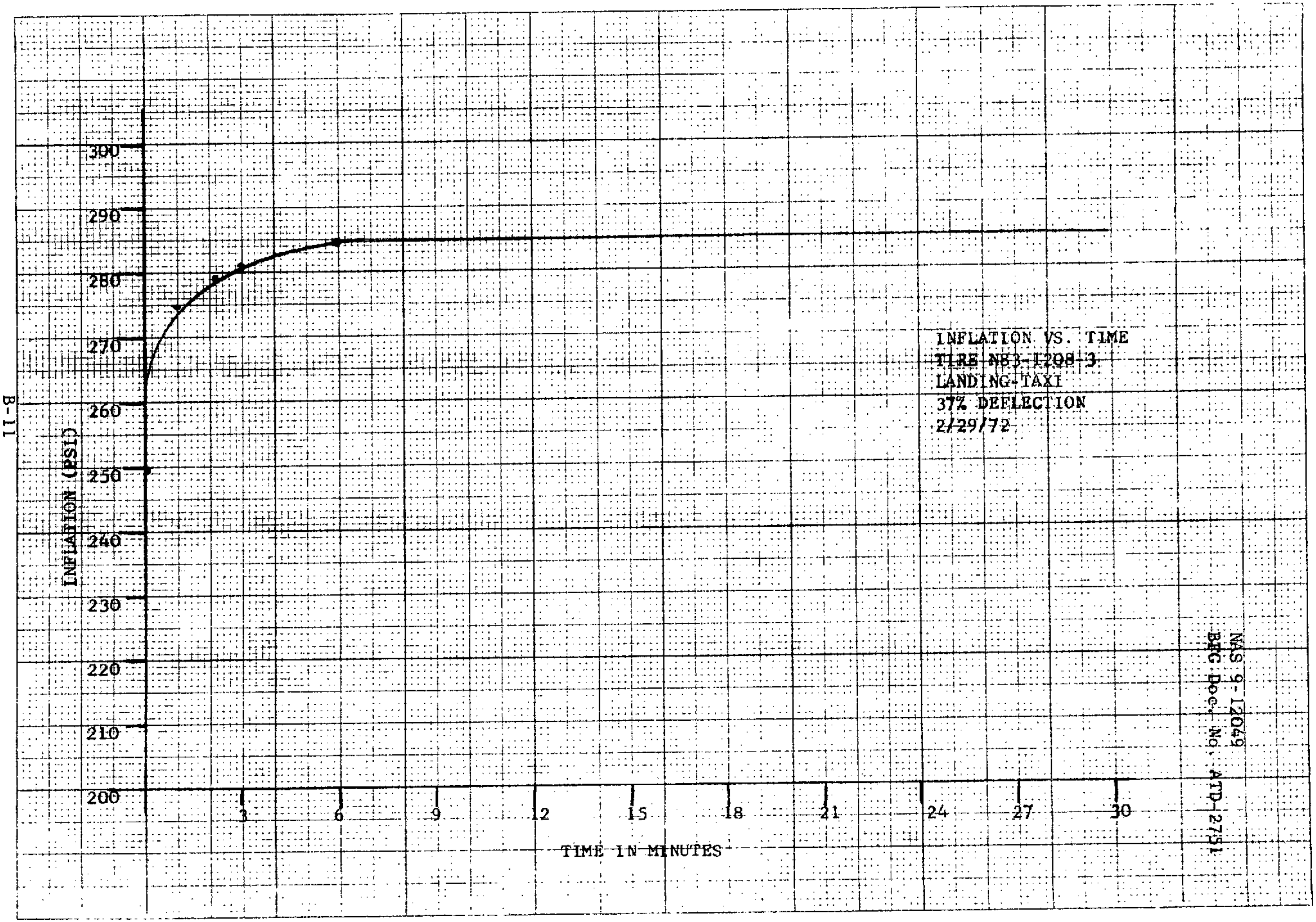

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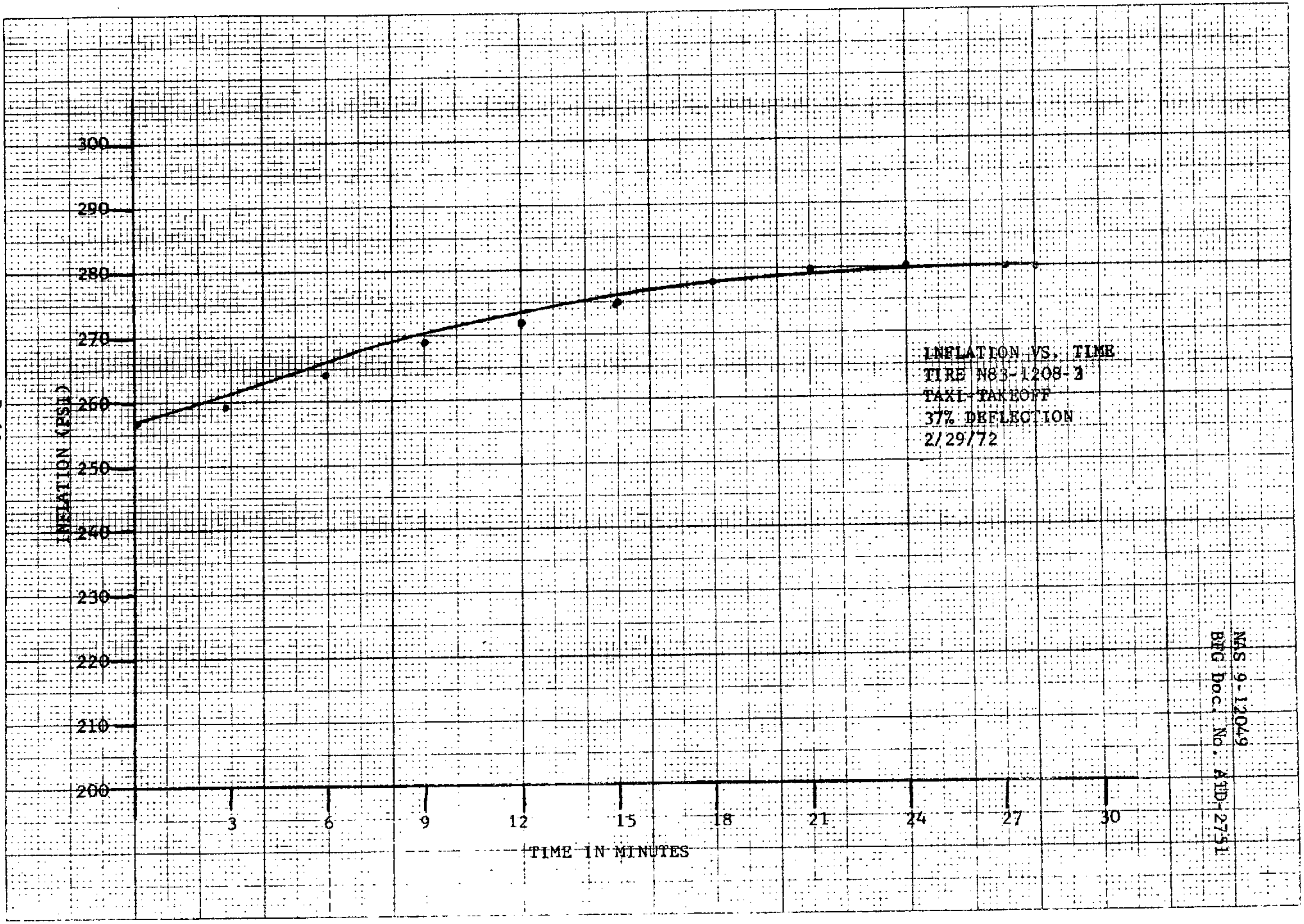

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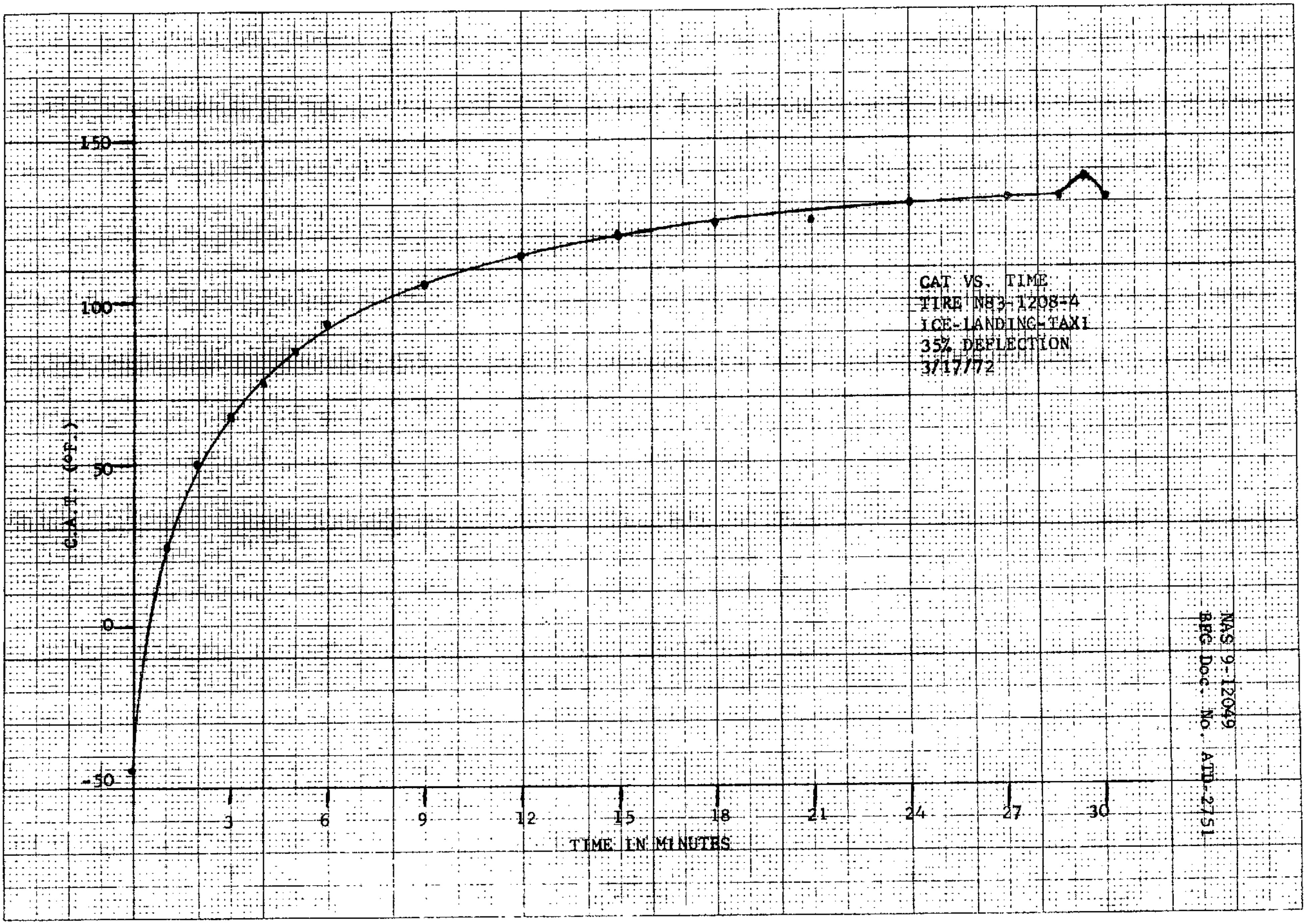
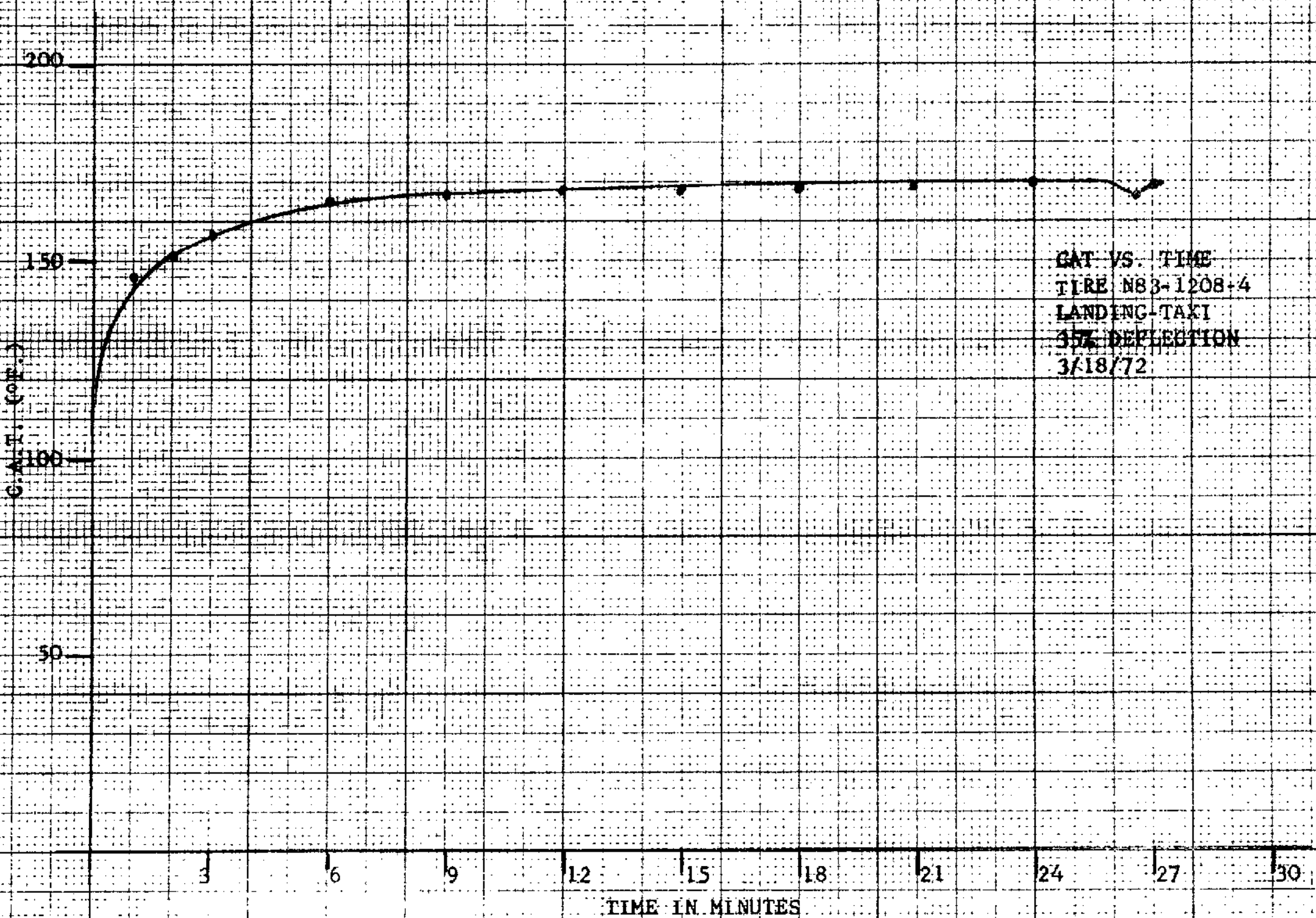

CAT VS. TIME
TIRE N83-1208-4
ICE-LANDING-TAXI
35% DEFLECTION
3/17/72
CAT (°F)
150
100
50
0
-50
3
6
9
12
15
18
21
24
27
30
TIME IN MINUTES



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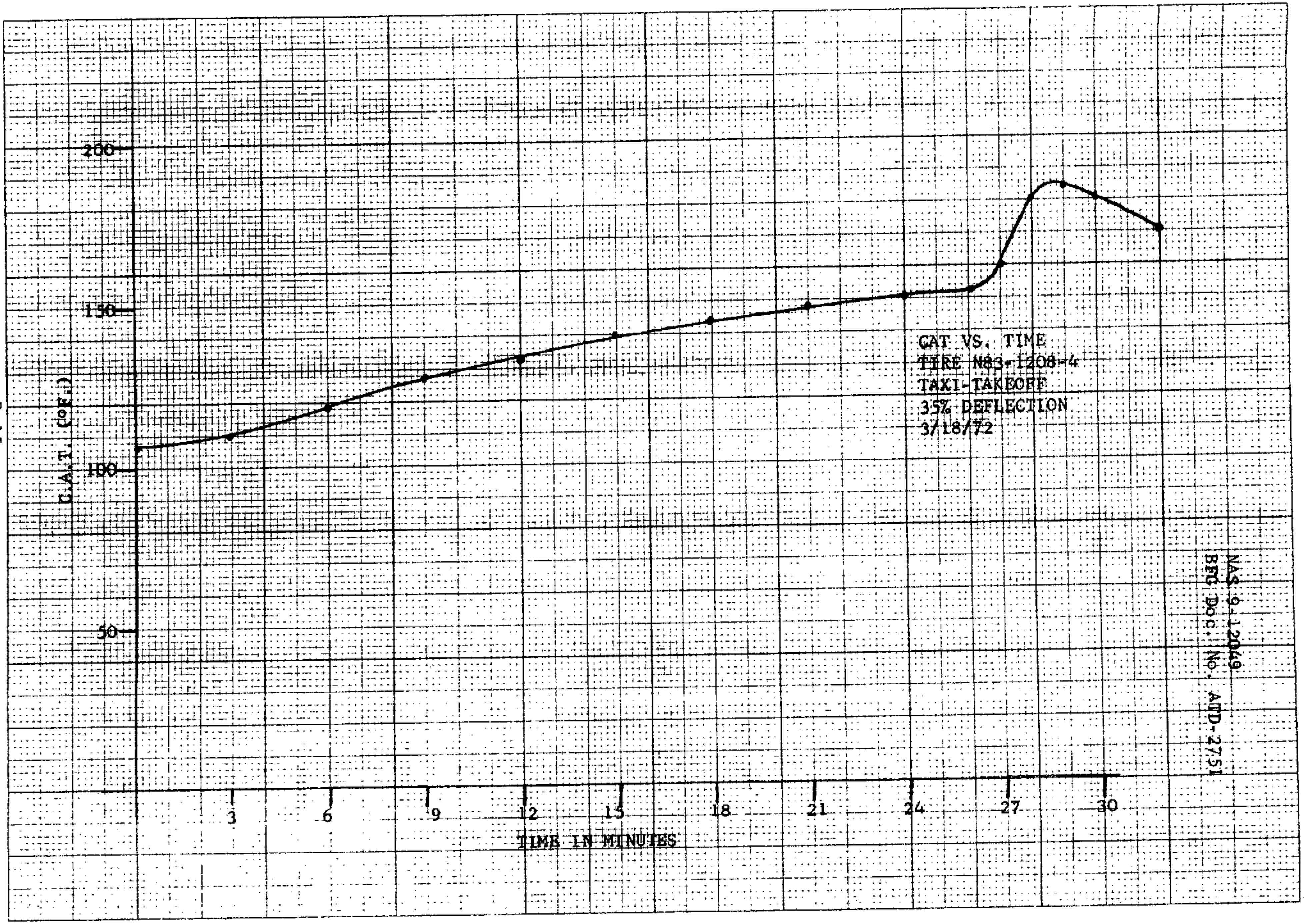

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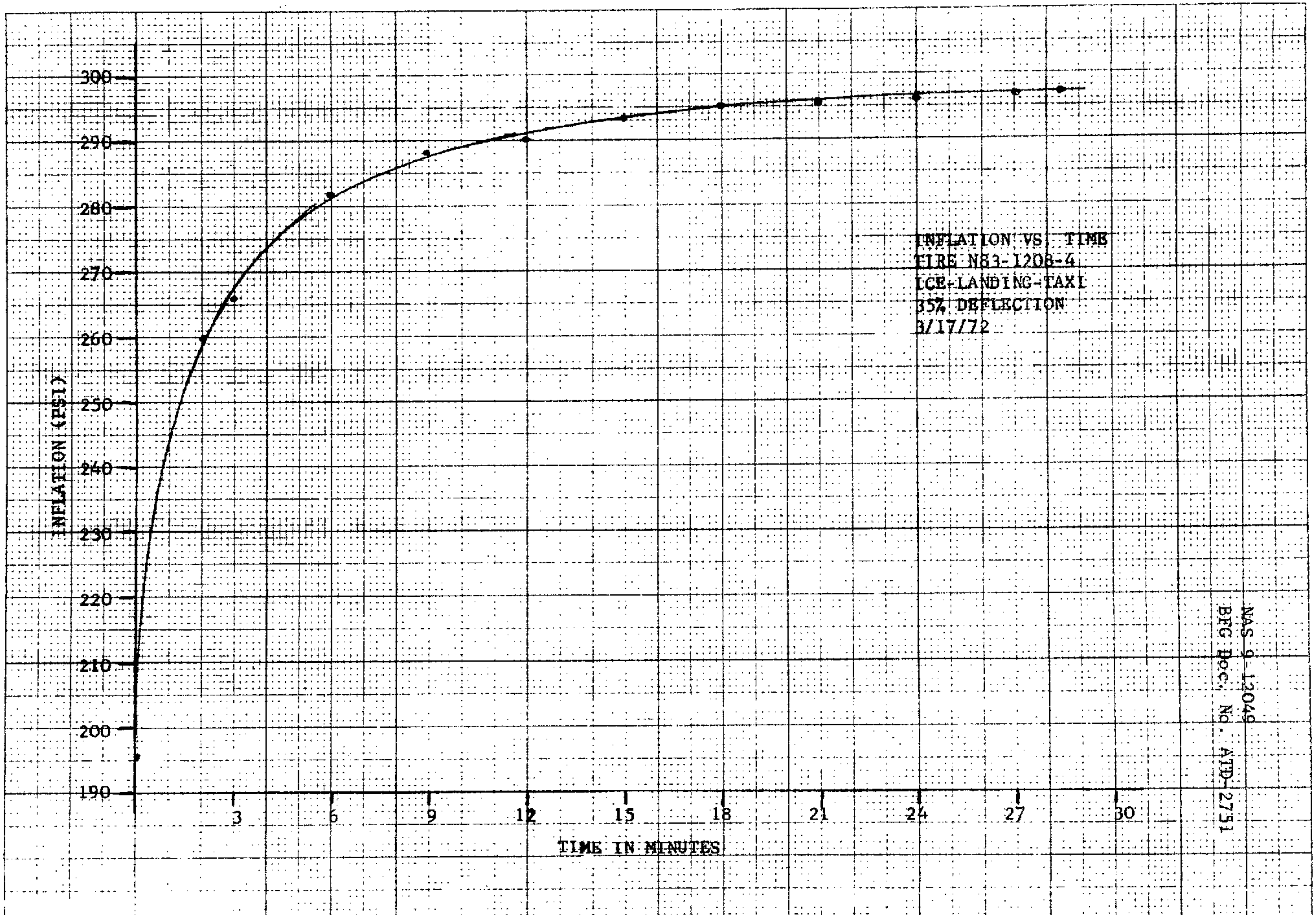

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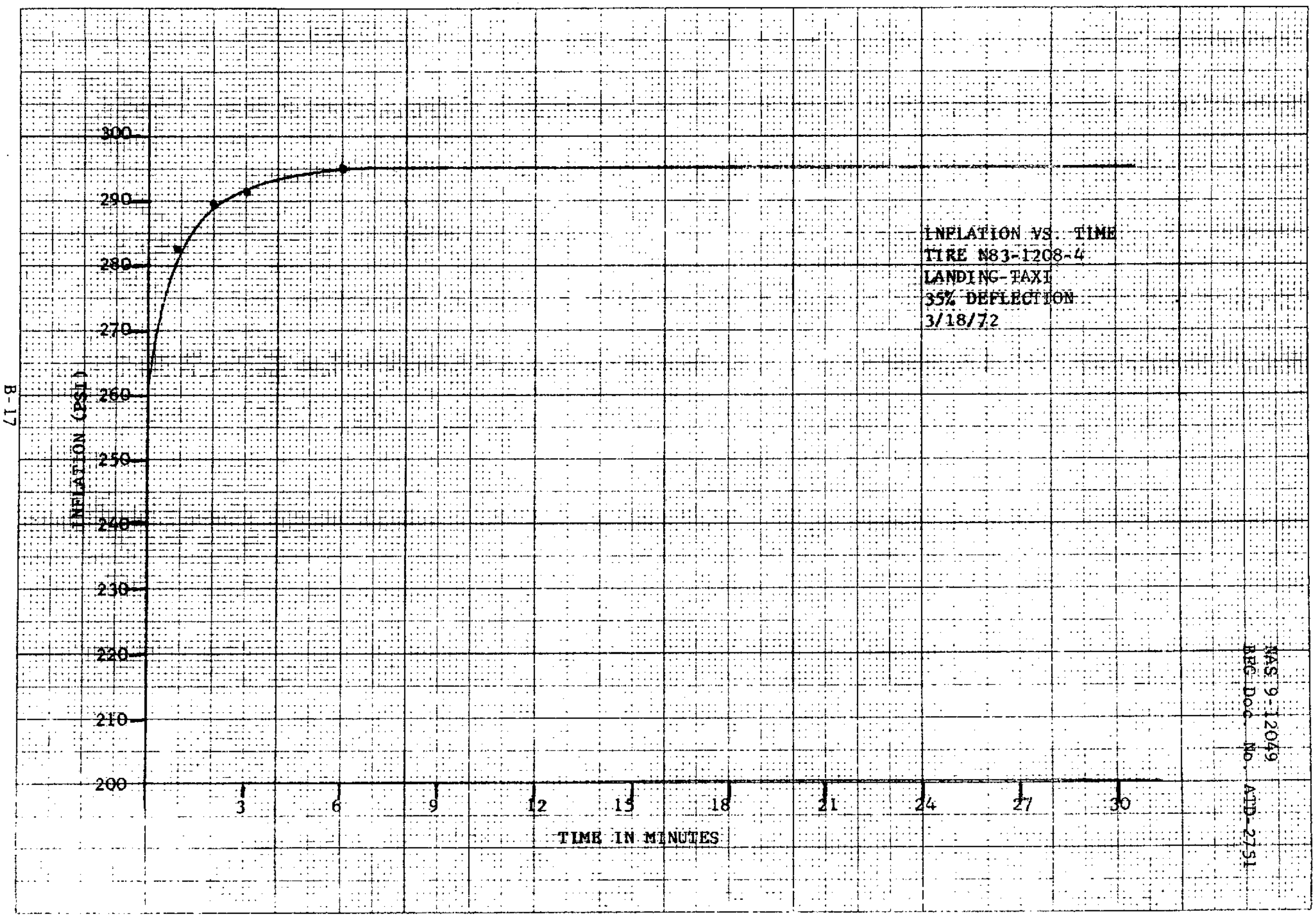
INFLATION VS. TIME
TIRE N83-1208-4
LANDING-TAXI
35% DEFLECTION
3/18/72
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280
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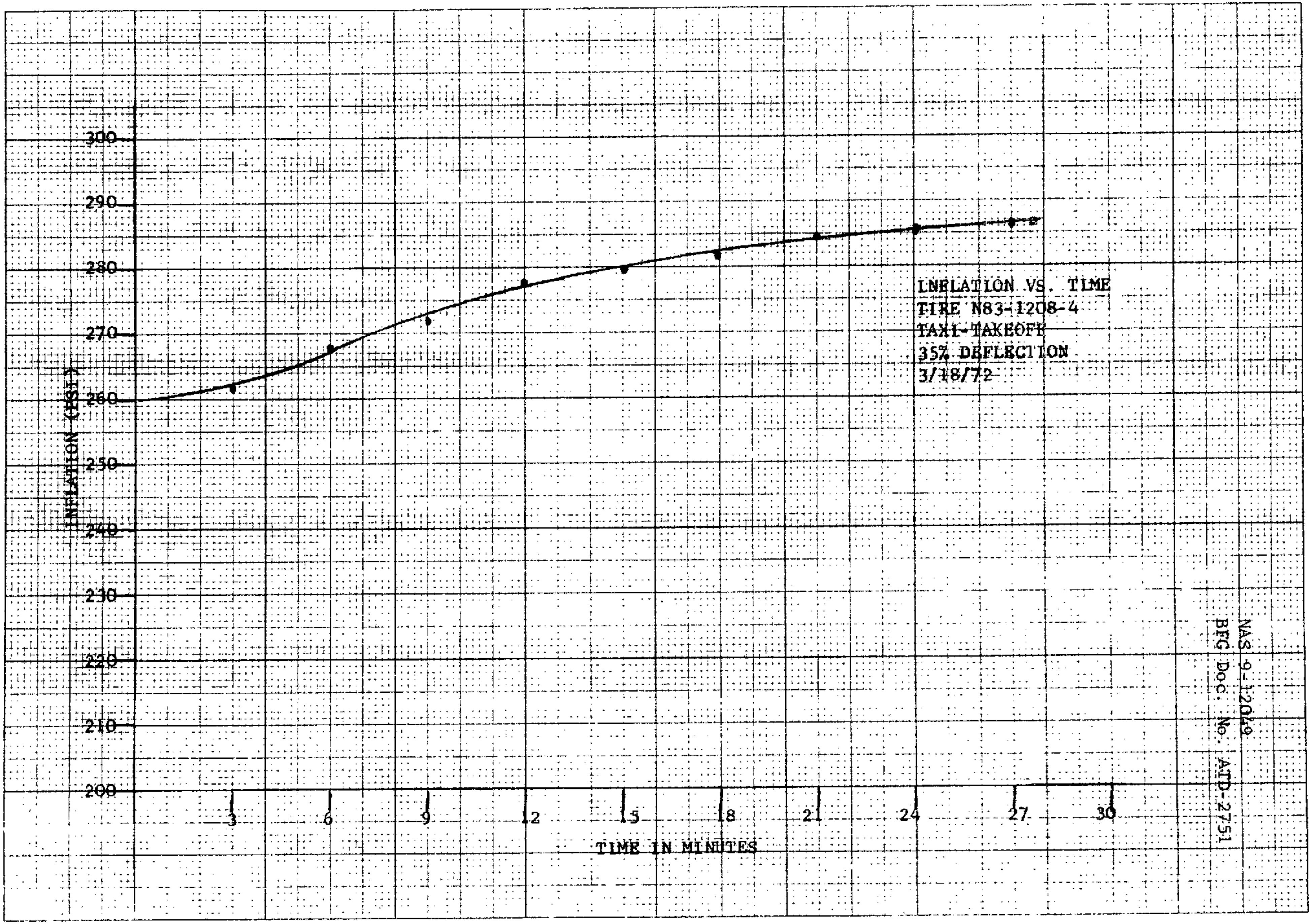

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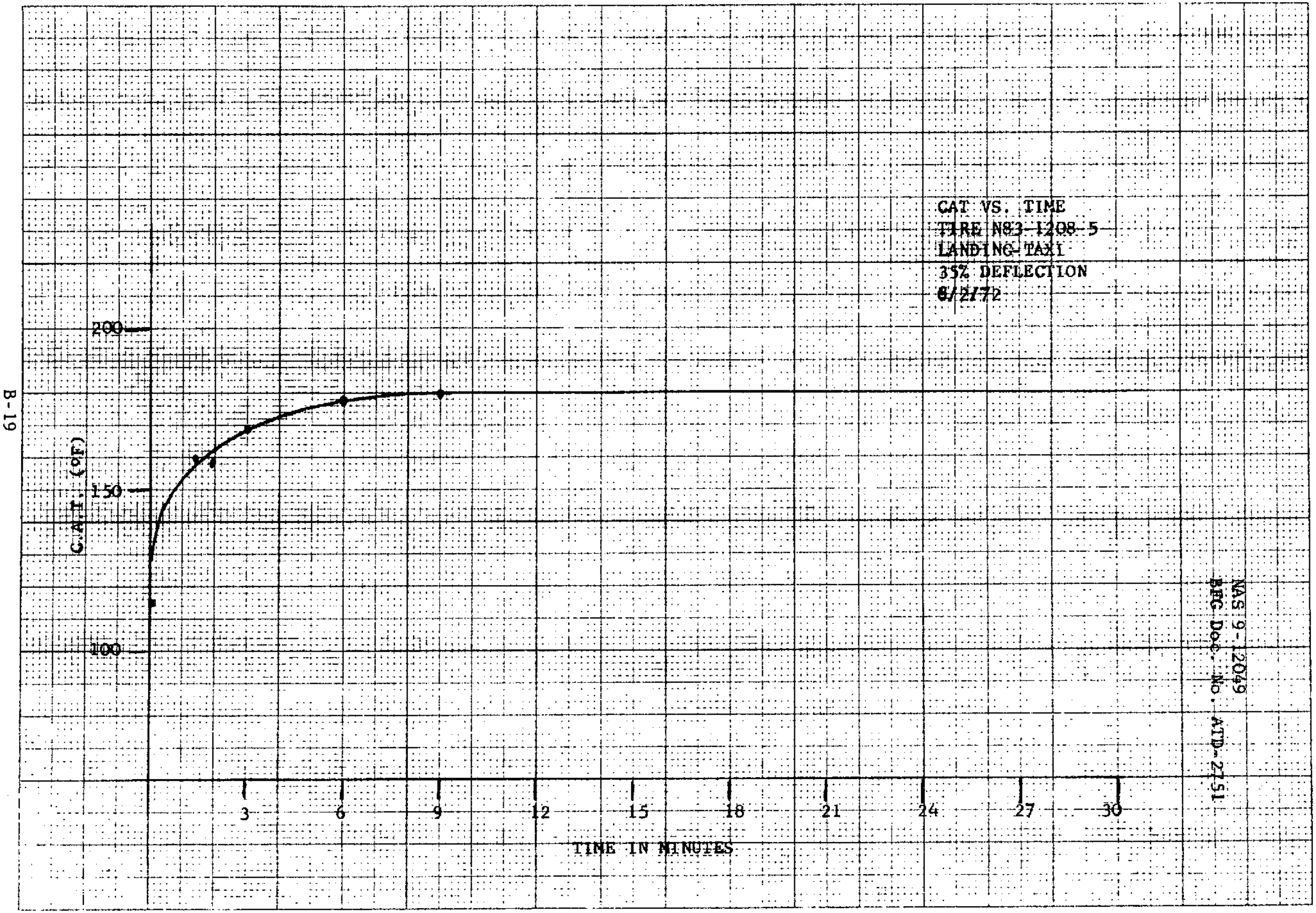

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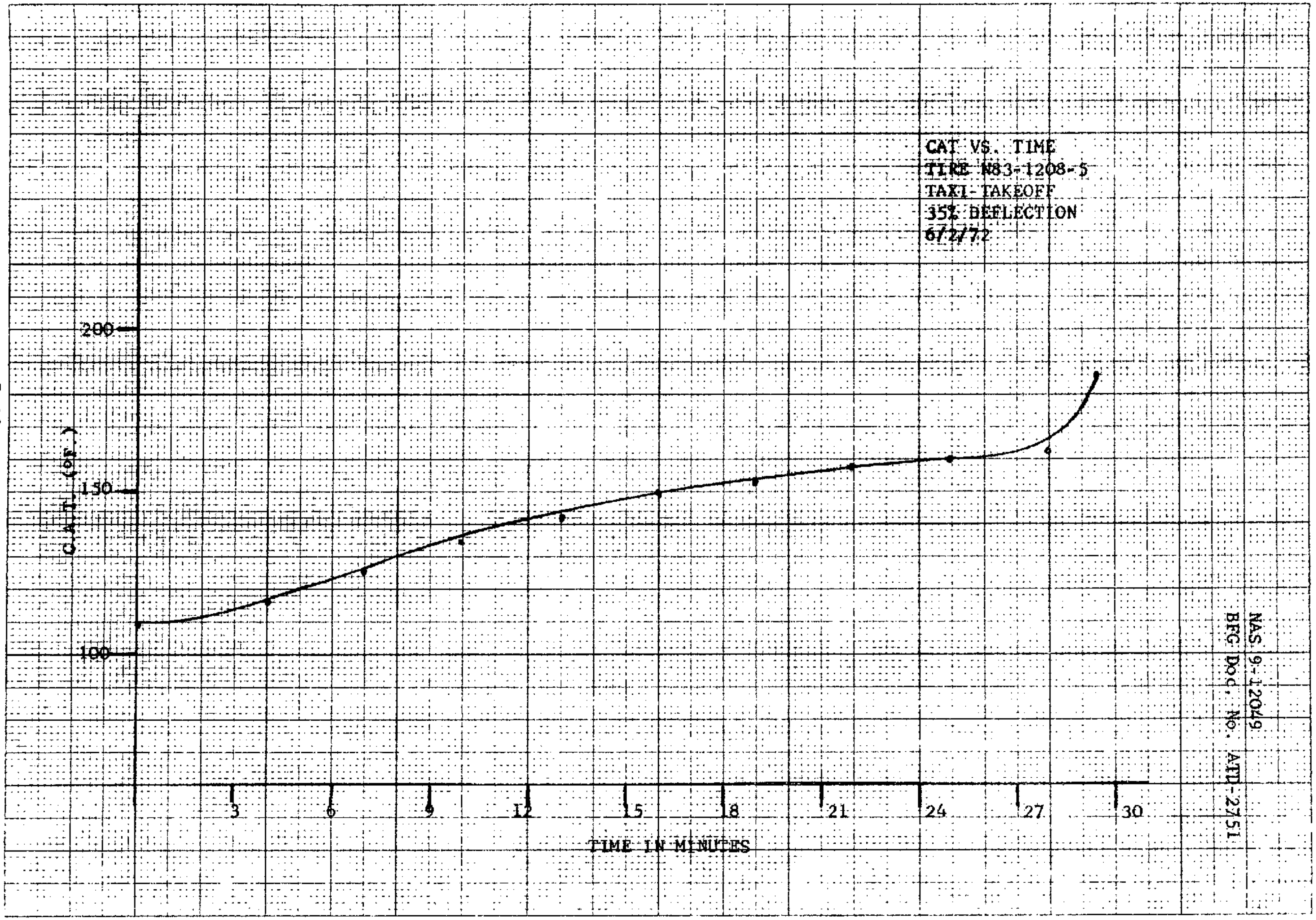

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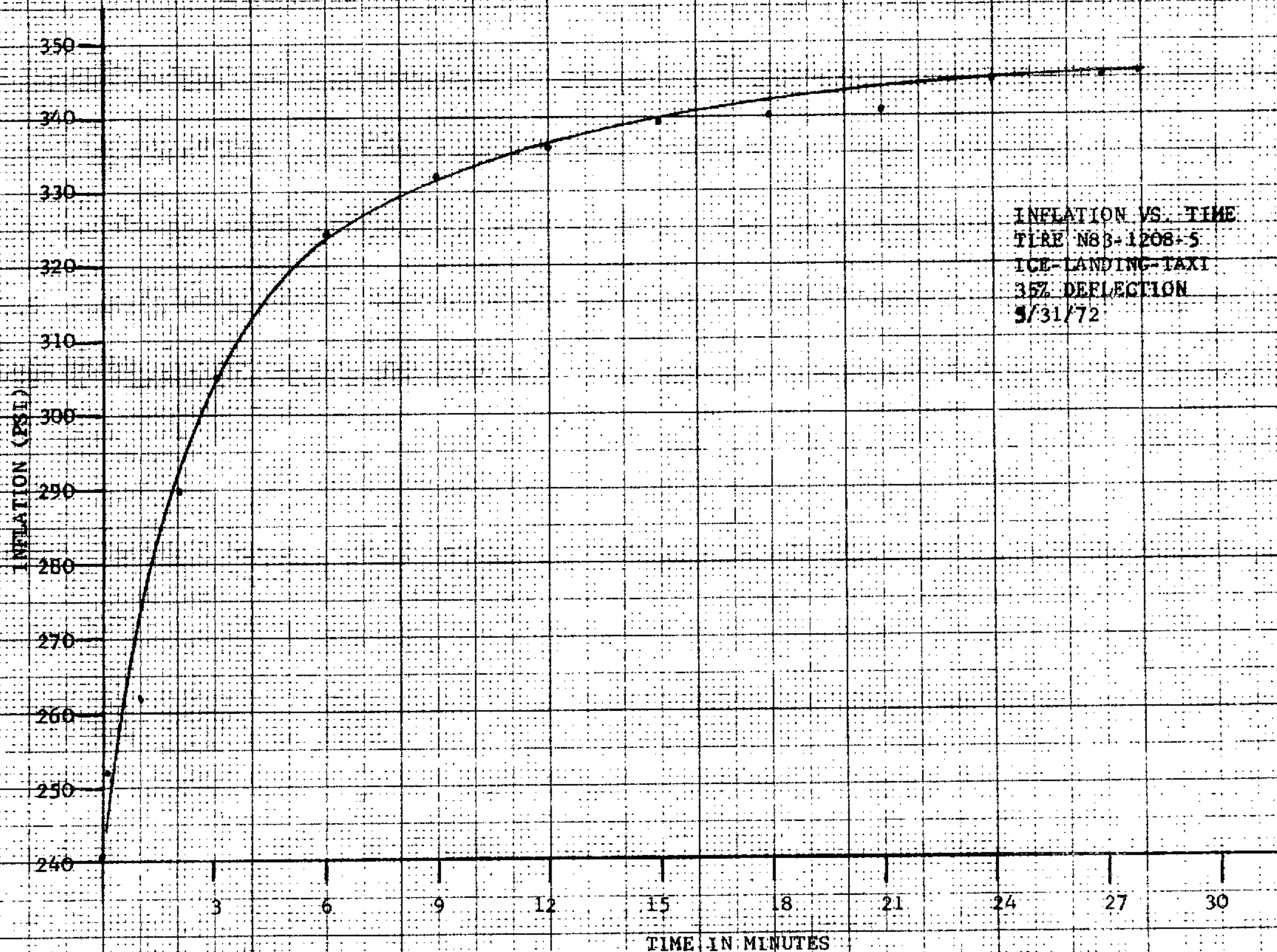

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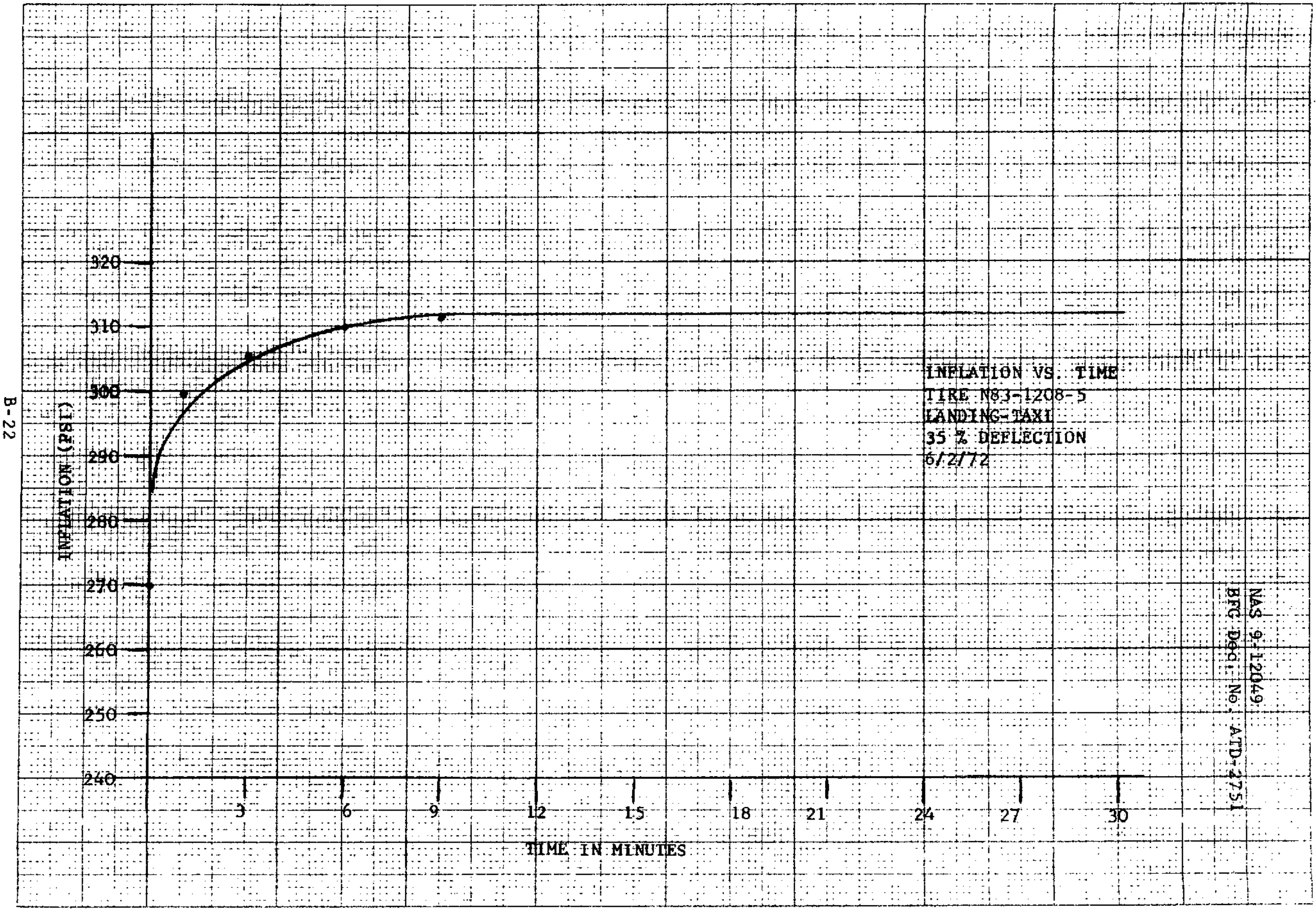
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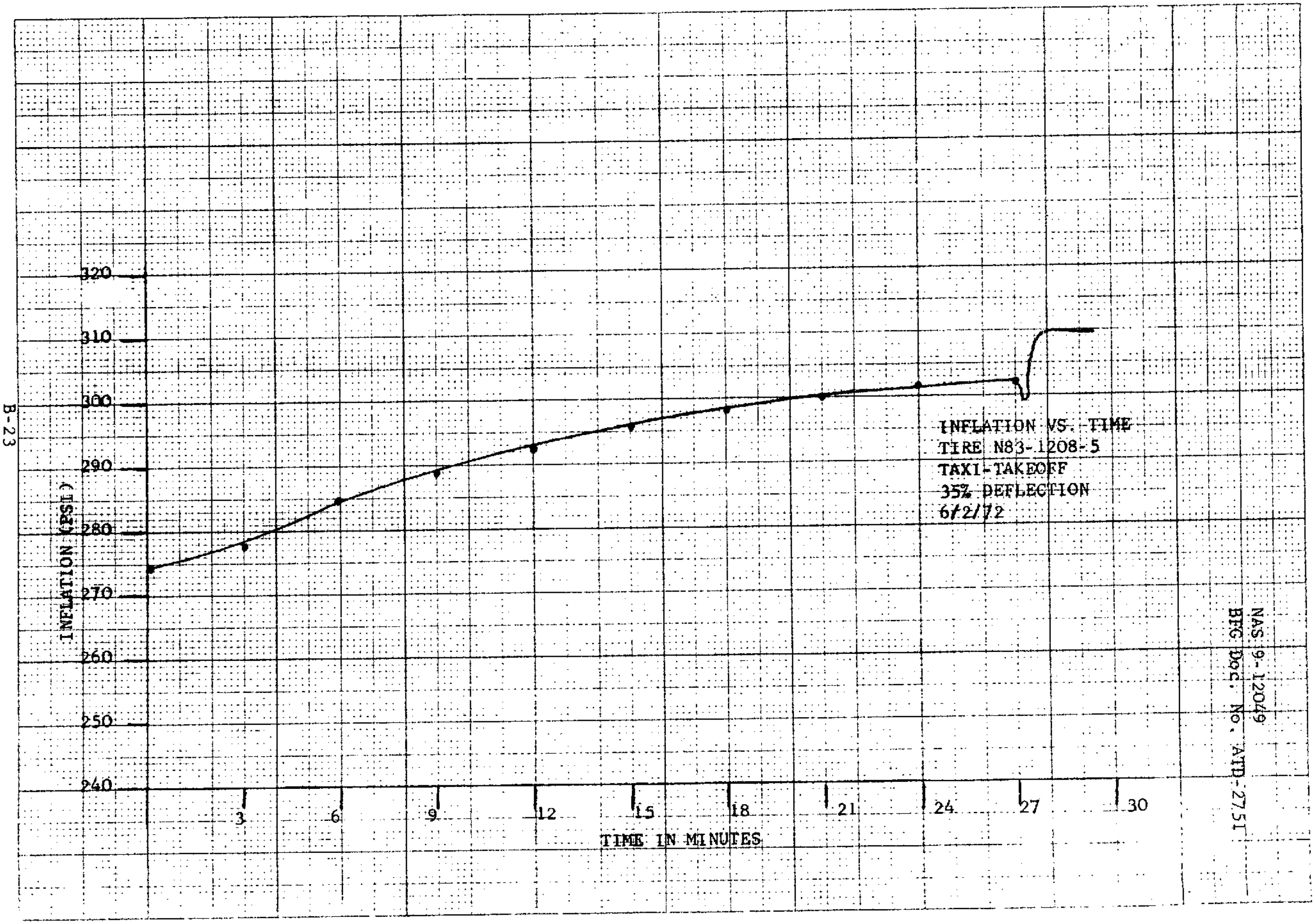

NAS 9-12049
BFG Doc. No. ATD-2751

APPENDIX C

NEW TECHNOLOGY REPORT

NEW TECHNOLOGY REPORT

All the testing was conducted using an existing 49x17 aircraft tire. This tire was found to perform satisfactorily in all tests. No new materials or construction techniques were required or developed.

Testing procedures were changed in some cases in order to simulate the space shuttle environment. These can be considered only variations of existing tests and not completely new testing methods.

APPENDIX D

SUMMARY OF RELIABILITY EFFORTS

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After the 35 per cent deflection condition was chosen as the one that was to be used, a second tire was subjected to twice the number of cycles as was the first. This tire was also cut and analyzed and found to have satisfactorily passed the testing.

APPENDIX E

SUMMARY OF SAFETY EFFORTS

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The most critical factors that must be controlled to insure safety in working with aircraft tires are heat and inflation pressure. In addition to adequate testing to insure that a given tire will perform satisfactorily under a given set of conditions, the most effective safety measure is the use of fuse plugs. These plugs are inserted in the wheel and are designed to release the inflation pressure within the tire if the temperature reaches a dangerous level.